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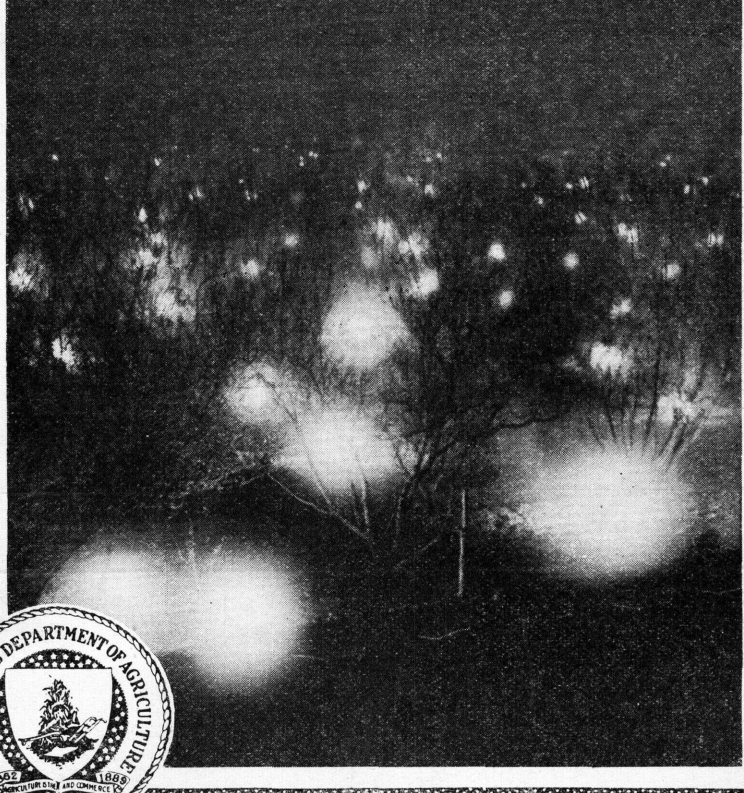
FROST AND THE PREVENTION OF FROST DAMAGE



ALL FROST-PROTECTION METHODS, from the simplest to the most complicated, can be carried on more successfully if the processes by which the earth's surface cools at night and the factors which influence the rate of cooling are well understood.

In the first part of this bulletin an attempt has been made to describe in a simple, elementary manner the changes that take place at and near the earth's surface on a frosty night, so that persons protecting plants or trees may be able to understand how their protective devices operate to prevent damage and in what manner they are most efficient. In treating a subject of this kind it is practically impossible to eliminate all technical terms, but so far as possible these have been carefully explained in simple language.

The larger portion is given over to a discussion of the various methods and devices now being used for protection against frost, together with a chapter on temperatures injurious to plants, blossoms, and fruit.

This bulletin is a revision of and supersedes Farmers' Bulletin 1096, Frost and the Prevention of Damage by It.

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FROST AND THE PREVENTION OF FROST DAMAGE

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FROST DEFINED

THE TERM "frost" or "hoarfrost" is used to designate the deposit of feathery ice crystals on the ground or other exposed surfaces the temperature of which has fallen to 32° F., the freezing point of water, or lower. It is customary, however, when such a temperature occurs to say that there was a "frost," even if it was not accompanied by a deposit of ice crystals.

Frosts are spoken of as light, heavy, or killing, depending on the degree of damage to growing crops. Since the same temperature that kills young tomato plants may not injure fruit blossoms, a frost that would be called "killing" by a gardener might be regarded as "light" by an orchardist.

In order to understand the underlying principles of frost protection it is necessary to know something of the methods by which the ground surface and lower air cool during the night.

HOW FROST IS FORMED

Whenever two objects, or different portions of the same object, have unequal temperatures, the colder always gains in heat at the expense of the warmer, unless prevented from doing so, the tendency being to equalize the temperature between the bodies or throughout every portion of the same body. The interchange of heat is accomplished in two ways, radiation and conduction, each of which will be discussed separately as it bears on the matter of the occurrence of frost.

RADIATION

The heat and light from the sun come to us through space in a manner called radiation. The atmosphere offers considerable obstruction to the passage of this radiation and rarely more than 65 per cent of it penetrates to the surface of the earth, even when the sky is very clear. A part of the radiant energy which reaches the earth's surface is lost through reflection, but the greater portion is absorbed, raising the temperature of the surface which it strikes. The region near the upper limits of the atmosphere is one of intense cold. The sun, having a much higher temperature than the earth, radiates heat to the earth, and in turn heat from the surface of the earth is radiated back to the much colder upper limits of the atmosphere.

The loss of heat through radiation from the earth is continuous both day and night, but during the day the amount received from the sun is usually much greater than that lost by radiation from the earth, and consequently the temperatures rises. After the sun sets, however, no heat is received from it to counterbalance the loss by outgoing radiation and the temperature falls.

CONDUCTION

Heat may be interchanged between different portions of the same body, or between two separate bodies in actual contact, by conduction. If one end of a bar of iron be held in a fire, the end away from the fire soon becomes too hot to hold in the hand, because the heat is transferred by conduction from the hotter portion to the cooler. The shortness of the time required for the heat to reach the cooler end of the bar indicates that iron is a relatively good conductor of heat. On the other hand, one end of a stick of wood may be kept in a fire until it is completely consumed without the other end becoming very warm; therefore wood is a poor conductor of heat. Both the soil and the air are very poor conductors of heat.

During a clear, calm day the temperature of the ground surface is raised by the heat received by radiation from the sun and the air in immediate contact with the ground becomes warmed by conduction. Since the air is a poor conductor, the heat of the ground is imparted to only a very thin layer of it at first. However, as soon as a small portion of this layer becomes warmer than the air above and around it, its density is lessened and it is forced upward and replaced by the cooler, denser air near by or above. This latter is also warmed, in turn, by conduction from the ground, and the process is repeated. The heated air continues to be forced upward until it reaches a point where its temperature is the same as that of the air surrounding it. This process continues until, near sundown, the temperature of the air is highest near the ground and decreases at a more or less uniform rate with increased distance above the ground up to a height of a thousand feet or more.

After the sun goes down, the ground cools rapidly through radiation and its temperature soon falls below that of the layer of air in contact with it. As soon as this occurs the surface air begins to lose heat to the ground by conduction. The air near the ground now

becomes cooler and denser than that above, and, instead of rising, as did the surface air during the day, it tends to be kept in contact with the ground by its density. Thus over a level plain on a clear, calm night we find a relatively thin layer of cold air near the ground, with often an increase in temperature by daylight up to an altitude of between 300 and 800 feet. (Fig. 1.)

AIR DRAINAGE

When the ground is gently sloping the force of gravity tends to cause this thin surface layer of cold air to move down the slope and gather in depressions in somewhat the same manner as water. The similarity between the flow of water and of air down a slope is inex-

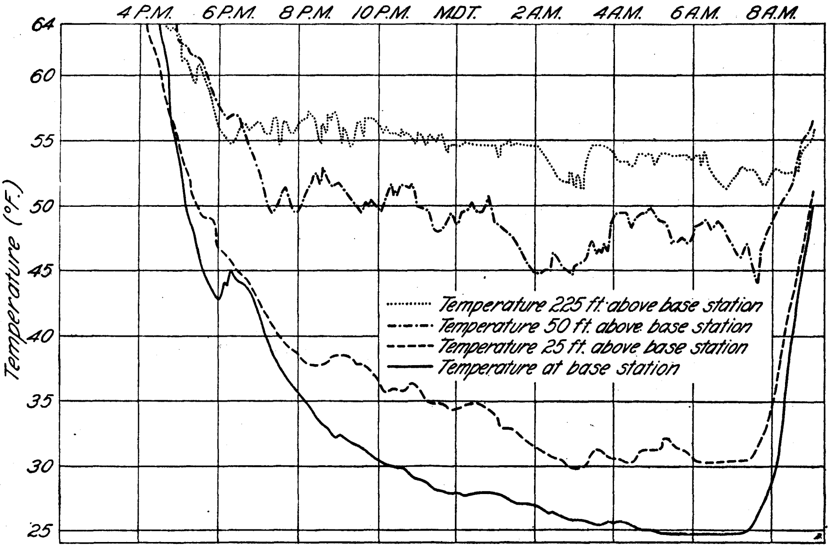


FIGURE 1.—Continuous records of the temperature from 4 p. m. to 9 a. m. at the base and at different heights above the base of a steep hillside, showing the great differences that sometimes develop on a clear, still night. Although the temperature at the base was low enough to cause considerable damage to fruit, the lowest at 225 feet above on the slope was only 51° F. Note that the duration of the lowest temperature was much shorter on the hillside than at the base

act, however, because of the difference between the physical characteristics of air and water. Water is practically incompressible; therefore neither its volume nor its density is much affected by a change in pressure. Air is a compressible gas and its physical condition is influenced greatly by such a change. The atmosphere exerts a pressure at sea level of about 15 pounds to the square inch, but with increasing elevation above sea level the pressure decreases. Because of its compressibility the density of the air decreases rapidly with increase in altitude. In accordance with a law governing the behavior of gases, a decrease in density is accompanied by a decrease in temperature and an increase in density by an increase in temperature. Therefore, when air moves downward along a gentle slope or a steep hillside, not only its pressure and density but also its temperature constantly increases. The rate of increase (heating by compression)

is about 1.6° F. for every 300 feet decrease in elevation, and an increase in elevation causes a decrease in temperature (cooling by expansion) at the same rate, provided there has been no loss or gain of heat from other sources.

Over a gently sloping plain or valley floor it is possible for the cold surface air to drain down the slope in much the same manner as water, as the vertical movement of the air takes place so slowly that the heating effect, due to decrease in altitude, is more than offset by the cooling due to contact with the ground which has been cooled by radiation. In the case of a steep hillside, however, movements of the surface air are more complex and have little similarity to the flow of water.

Like the more nearly level lower ground, the surfaces of slopes and summits of hills and ridges lose their heat rapidly, through radiation, after sundown, and their temperatures fall. The air in immediate contact with them also cools, through conduction, so that it is soon cooler than the air at some distance out over the valley at the same elevation.

As this cooler air in contact with the hillside flows downward directly along the surface of the ground, its altitude decreases more or less rapidly, according to the steepness of the slope, and its density increases. If no further cooling takes place, it will be surrounded by air increasingly colder as it nears the valley floor, while its own temperature tends to increase because of the compression it undergoes. As soon as a position is reached where it has the same temperature as the air surrounding it, the downward movement ceases. (Fig. 1.) Well-rounded summits of low hills are nearly always cooler than the slopes below on clear, calm nights, because of the more effective air drainage on the steeper slopes.

The drainage of cold air down a valley floor is usually interfered with considerably by outside influences. As soon as the flow begins there is more or less mixing of the colder lower air with the warmer upper air, and inequalities in barometric pressure over a large area may temporarily prevent the flow, or even reverse its direction for short periods. Local winds of slight velocity and covering a very limited area often effect a mixing of the air which causes the surface temperature to rise suddenly as much as 5° to 10°. (Fig. 2.) It is not often possible to know in advance that the drift of the air on a valley floor will continue from one direction during a cold night, though there may be one particular direction from which it very seldom comes.

EFFECT OF WATER VAPOR ON RATE OF COOLING

Water vapor is the most effective of the various gases present in the atmosphere in intercepting radiation of heat from the earth. Therefore, the amount of water vapor present in the atmosphere above a given locality has considerable influence on the rate of fall in temperature at that place during the night; the temperature falls more slowly when the humidity is high than when it is low, other conditions being the same. (Fig. 2.)

The amount of invisible water vapor in the atmosphere varies greatly at different times. At a given temperature only a certain maximum amount can be present. If the temperature falls when the

maximum amount is present a portion of the water vapor is changed to liquid or frozen water, as the amount of water vapor which can be present in the air is greater when its temperature is high than when it is low. No matter how dry the air under natural conditions may be, if its temperature be lowered sufficiently, a point will be reached where the invisible vapor will begin to appear in a liquid or frozen form. The temperature at which this condensation begins is called the dew point. The drops of moisture which appear on the outside of a pitcher of ice water on a warm day are formed through the chilling of the air in contact with the pitcher. These droplets begin to appear on the pitcher as soon as its temperature has reached the dew point.

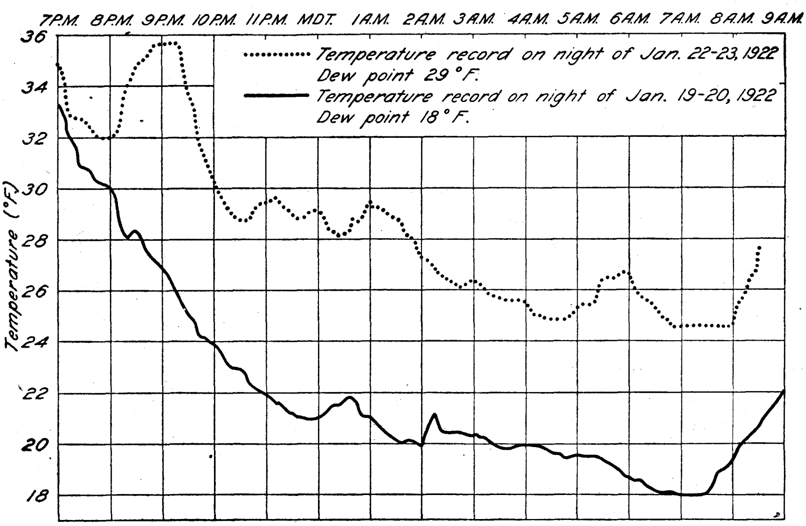


FIG. 2.—Continuous records of the temperature from 7 p. m. to 9 a. m. at the same station during two different nights of the 1922 freeze in southern California. The upper record (dotted line) indicates the temperature on the night of January 22–23, when the dew point was 29° F., and the lower (solid line) that on the night of January 19–20, when the dew point was 18° F. Note that a few minutes after 7 p. m. the temperature was practically the same on both nights. The sudden rise between 8 p. m. and 9 p. m. in the upper record was caused by wind. These records illustrate the effect of varying amounts of moisture in the air, as shown by the dew point, on the rate at which the temperature falls at night

The actual amount of water vapor in the air expressed in terms of weight per given volume of air, is called absolute humidity. The term " humidity " as used in this bulletin refers to absolute humidity.

As a general rule, especially when there is considerable moisture present, the temperature of any exposed object falls more or less steadily after sunset until it reaches the dew point, at which time the invisible water vapor in the atmosphere begins to condense and be deposited on it. If the dew point is above 32° F., the freezing point of water, dew is formed; if it is 32° F. or lower, frost forms. Since dew or frost does not begin to form until the temperature of the ground or other object reaches the dew point, it is apparent that if the dew point is very low, the temperature may fall low enough to cause considerable damage without the formation of any frost. For example, if the dew point is 18° F. and the lowest temperature

reached during the night is 24° F., there will be considerable damage to growing crops without any deposit of frost whatever. This phenomenon is often called a "black frost."

Another factor that has great influence on the amount of fall in temperature during the night is the liberation of latent heat in the formation of dew or frost. If a pan of water having a temperature of 40° F. be placed over a gas flame and a thermometer placed in the water, the thermometer will register a steady increase in temperature until the water begins to boil. The heat from the burning gas has been used to raise the temperature of the cool water. After the boiling point is reached, the thermometer will show a stationary temperature as long as any water is left. Even if the amount of heat is doubled, the water will only boil away more rapidly. The additional heat, after the water begins to boil, is used up in changing it from a liquid to a vapor. The heat required to vaporize water becomes a property of the vapor and is liberated when the vapor condenses and becomes liquid again. Thus, water vapor contains a great amount of stored or latent heat, which is given up when condensation takes place.

A portion of the sun's heat during the day is expended in evaporating moisture from the ground and from the leaves of plants. When the temperature falls to the dew point at night and vapor is condensed, its latent heat is given up. The amount of heat released on a particular night depends on the amount of moisture condensed; the greater the amount of moisture in the atmosphere, the more will be condensed, provided the temperature falls below the dew point. When the dew point is high, indicating much moisture, the latent heat given off in the formation of dew is often sufficient to check the fall in temperature almost entirely for an hour or more. Generally speaking, therefore, other conditions being equal, the higher the dew point in the evening the less danger there is of the occurrence of a damaging frost. If dew begins to form on vegetation when the temperature has fallen to 45° F., the temperature fall during the remainder of the night will be comparatively slow. (Fig. 2.)

Heat is liberated also when the moisture on vegetation or in the surface soil freezes. When the ground is wet from previous heavy rains the fall in temperature is therefore likely to be checked when the freezing point is reached. After most of the ground moisture has been frozen, the temperature usually falls more rapidly.

WHEN TO EXPECT FROST

The weather in the latitude of the United States is controlled by atmospheric disturbances of great size and varying intensity, which follow one another across the country, moving usually from west to east. These disturbances are of two types, one of which is marked by low barometer, overcast skies, and rain or snow, the other by high barometer and clear skies.

The main factor in the occurrence of frost is radiation of heat from the earth. When heavy lower clouds cover the sky they send back much radiation to the earth below, thus keeping it relatively warm and preventing the occurrence of frost. A moderate wind is also generally effective in preventing frost through the mixing of the warmer air above with the colder surface air.

The important requirements for the occurrence of a frost, a clear sky and little wind, are present during the passage of an area of high barometer. As an area of low barometer, with overcast skies and rain, nearly always precedes an area of high barometer, the saying in many sections of the country, "Three days rain and then a frost" has some basis.

During the passage of a well-defined area of low barometer the radiation from the sun is more or less completely cut off by heavy clouds and the ground is not warmed much during the day. If rain has fallen, the evaporation from the wet ground uses up a great deal of heat, and this also tends to keep the temperature low during the day. Therefore on the first clear night after a rain during the frost season the temperature at sunset is likely to be comparatively low, and not much cooling by radiation is necessary to form frost, although it may not occur in many cases on the first night because of wind conditions.

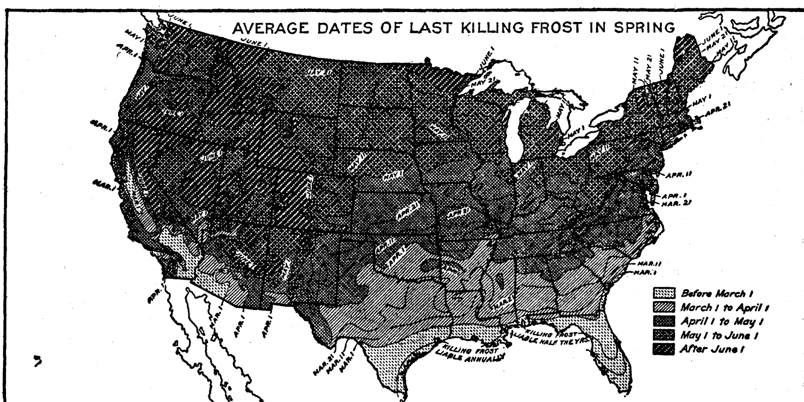


FIG. 3.—Average date of last killing frost in spring. In half the years it will occur earlier than the dates shown and in half the years later than these dates

Though the moisture in the ground after a rain tends to prevent warming of the ground during the day, it also tends to prevent a large fall in temperature during the night, as the water vapor taken up by the atmosphere from the wet ground diminishes cooling. When the dew point is reached the latent heat given up checks the rate of cooling still more, and when freezing converts the ground moisture into ice the liberated heat also aids in checking the fall in temperature.

By the second night after the rain the surface of the ground has usually dried out considerably, the dew point is likely to be lower, and there is more danger of a damaging frost. Before the third night, the day temperature has usually risen high enough to make unlikely the occurrence of a heavy frost, but frost may occur as late as the fourth night when the high-pressure area is extensive, well defined, and moving slowly.

Large bodies of water exert a modifying influence on the climate of localities to the leeward, and such localities are less liable to damage by frost. A light wind blowing from a large body of water

is generally more or less laden with water vapor, which retards the rate of surface cooling; and as the temperature of the water is usually considerably above freezing, that of the air passing from it to the land is often high enough to prevent the formation of frost.

Rivers often give up a large amount of moisture to the surface air, so that when the temperature falls to the dew point a fog forms which covers a part or all of the lower land in the valley, absorbing and returning radiation, and preventing a rapid further fall in temperature. In valleys near the ocean, fog sometimes drifts in from the water toward morning and prevents a damaging frost. On nights with fog the hillsides are practically always colder than the lowlands unless the fog extends high enough to cover both hillsides and valley floor.

Although heavy low clouds emit much radiation to the earth, high thin cirrus clouds, which are composed of tiny particles of ice, have

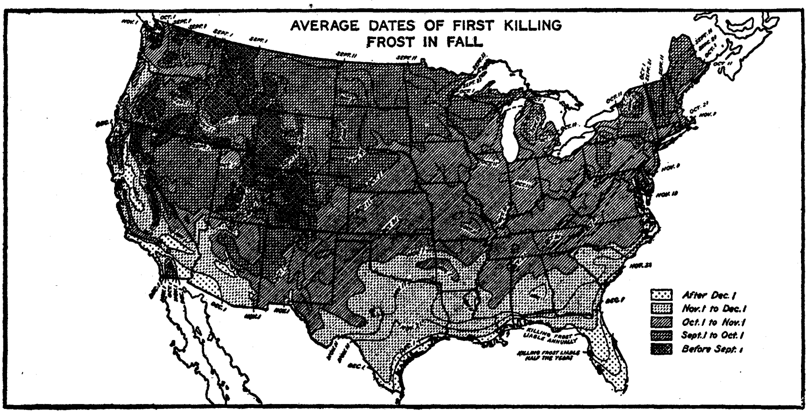


FIG. 4.—Average dates of first killing frost in fall, by which time it may be expected to occur in half the years and in half the years later than these dates

far less effect on surface temperatures, as they radiate but little. Heavy frosts sometimes occur when the sky is completely covered with cirrus clouds.

INFLUENCE OF SOIL AND VEGETATION ON MINIMUM TEMPERATURE

In experiments carried on in the cranberry bogs of Wisconsin, H. J. Cox found differences of from 5° to 10° F. between minimum temperatures registered on the surface of the level ground at two points within 6 feet of each other. The ground at the warmer station was bare, while that at the colder station was covered with sphagnum moss. The soil at both points was peat. At a height of 3 feet above the ground this difference in temperature disappeared.

Professor Cox attributed this difference in temperature to unequal warming of the bare and moss-covered soil during the day and unequal conduction of heat to the surface from below during the night. The soil at the cooler station was shaded by the moss, and a large part of the heat received during the day was expended in evaporating water from the plants, while at the warmer station the sun shone directly on the soil, warming it to a greater depth. At night the

heat absorbed during the day was slowly conducted to the surface of the bare ground, while most of the smaller amount of heat absorbed by the moss-covered ground was prevented from reaching the thermometer because of the intervening moss, which is a poor conductor of heat.

It was also found that the temperature often fell several degrees lower at night over wet ground than over dry ground, because of the heat expended in evaporating moisture from the wet ground during the day. When the bogs are covered with coarse sand, the moisture is prevented from rising to the surface from below, and there is less cooling by evaporation. Thus by keeping the bog free from weeds, draining, and sanding, damage by frost may be greatly lessened.

In some parts of the United States fruit growers have believed that the growing of a cover crop in an orchard greatly increases the frost hazard, while some growers believe the opposite. A careful investigation by the Weather Bureau has proved that while the temperature actually is lowered by the presence of a cover crop in an orange grove the amount of the depression is slight, amounting on the average to about 0.5° F. at a height of 5 feet above the ground, and 1.3° F. at a height of 10 inches above the ground. On nights when the temperature barely reaches the danger point in clean-cultivated orange or lemon groves the lower temperature in groves with cover crops may cause the loss of some fruit within 3 feet of the ground, but the fruit in the upper portion of the tree is not likely to be affected. The presence of cover crops in mature deciduous orchards probably has little or no effect on the frost hazard, since the lower branches of the trees usually are 5 feet or more above the ground.

PROTECTION FROM FROST

Since a crop which represents the results of the labor and care of an entire season may be destroyed by frost in a single night, various methods of protection against frost have been practiced for centuries in different parts of the world.

The three general principles used in frost-protection devices in the United States are the following:

(1) Conserving heat, (2) mixing or stirring the air, and (3) adding heat.

CONSERVING HEAT

The most important method by which the ground cools during the night is through loss of heat by radiation, and if the heat is conserved sufficiently there will be no damage. This may be partially accomplished by covering the ground or plants with various materials.

COVERING WITH GLASS

Glass is one of the best materials known for screening plants and preventing frost damage, since it allows the incoming radiation from the sun to pass through it freely, but is almost impervious to that outgoing from the earth. The cost of covering with glass, however, is too great to permit its use, except for the more expensive plants and flowers.

CLOTH SCREENS

Experiments have been made in California and elsewhere to determine the value of a covering of cloth over orchards and over individual trees. When an acre or more of orchard is thus covered, the minimum temperature may be from 2° to 4° higher inside the covered area than outside if there is little air movement. In cooperative tests conducted by the Weather Bureau and the southern Oregon experiment station of the Oregon Agricultural College it was found that cloth coverings over small areas of an orchard, or over individual trees, do not have an appreciable effect on the temperature, even when composed of heavy material, such as canvas.

Coverings of rather heavy cloth laid directly over garden truck or other low-growing plants are effective in protecting against moderate frosts. In this case the heat of the ground is conserved by the cloth covering, and the air movement is so slight near the ground that there is little tendency for the cold outside air to pass under or through the covering. The temperature of the surface of the cloth exposed to the sky is lowered by radiation and may fall to a low point, but as both the cloth itself and the air underneath are very poor conductors of heat, the temperature of the plants under cover falls much more slowly. The heat which has penetrated a few inches into the ground during the day is slowly conducted to the surface during the night and aids in keeping the temperature under the cover above the freezing point.

During the spring of 1928 about three-fourths of an acre of 2-year-old Clark seedling strawberry vines at Kennewick, Wash., were covered with burlap to determine its effectiveness as a protection from frost damage. The covering was a single thickness, made by sewing second-hand sacks in strips 36 inches wide and 185 feet long, the length of the rows covered. The strips were placed on the vines by being unrolled from an improvised reel made with buggy wheels, two rows being covered at a time. The covering remained in place over the vines for three consecutive days and nights during the blooming period, and, through interfering with pollination, probably was responsible for a slight reduction noted in the crop, as compared with another portion of the same patch which was protected with heaters.

A clear-liquid alcohol thermometer placed under the burlap covering showed an average temperature 5.3° F. higher than that indicated by a similar thermometer placed on the surface of the vines outside the covering and exposed to the sky but only 1.1° F. higher than that in an instrument shelter set on the surface of the vines, with the thermometer 10 inches above the ground. The experiment proved that a burlap covering furnishes adequate protection against a light frost, but that the cost of such protection, which amounted to approximately $117 per acre per year in this particular case, is almost prohibitive. Apparently the vines or blossoms were not injured by the weight of the burlap.

It is evident that when a frost is expected cloth or paper coverings should be placed early in the evening, before much of the heat accumulated in the soil during the day has been lost and should be removed as soon after sunrise as possible. Tin cans or other metal

coverings should not be used to protect plants from frost damage. Metals are good radiators and conductors of heat, and the temperature is likely to fall as low under a covering of this kind as in the outside air.

LATH SCREENS

Screens made of laths fastened together with wire (the spaces between them being about the width of the laths) have been used in Florida and California to protect orchards. These screens not only conserve heat during the night but also serve as a shade from the sun. About three-fourths of the sky is screened by a covering of this kind. Lath screens are satisfactory for use in protecting nursery stock but should not be placed over mature trees, as the trees will suffer for lack of sunlight during the day.

Orchard heaters burned under screens of lath or cloth are more effective in raising the temperature than when burned in an uncovered orchard.

OTHER METHODS

Paper covers may be used to protect small individual plants or large paper strips to protect gardens against light frosts. Generally speaking, paper coverings do not afford as much protection as those made of heavy cloth.

In December, 1927, two navel-orange trees in southern California were covered with large bags made of waterproof paper to determine how much protection such covering would furnish. The paper tents were left in place continuously 11 days and nights, and at the end of this period they were damaged in a wind and rain storm. Minimum temperatures on cold nights averaged only about 1.5° F. higher inside the tents than at the check station outside. On the coldest night the minimum inside the tents was 27° F. and at the check station, 25.1° F. On clear days maximum temperatures 5 feet above the ground inside the tents averaged 17° F. higher than in an instrument shelter outside, and at 7 feet above the ground, 23.8° F. higher.

Moisture transpired by the trees maintained an extremely high humidity inside the tents and, throughout the experimental period, the leaves were covered with moisture practically all of the time. The high day temperatures and high humidity caused the leaves to become very tender and susceptible to frost damage, and all the foliage in contact with the tents was severely damaged or killed when the outside temperature fell to 25.1° F. The foliage on trees not covered was not damaged.

The results of this experiment show definitely that paper tents left in place over the trees continuously for several days and nights are not satisfactory as a means of frost protection.

In parts of Alabama and Florida mounds of earth are piled around small citrus trees in the fall, covering the trunk up to above the bud union so as to protect the scion. A severe freeze may kill all that portion of the tree above the earth covering, but the trunk is not injured and a new top can be grown in much less time than a new tree.

In California citrus trees under 6 years of age are sometimes protected by wrapping the trunks with cornstalks or tules. The covering material should be 2 to 3 inches thick, and bound tightly to the trunk,

reaching from the ground up to the head of the tree. Any space left between the base of the covering and the ground should be covered by heaping soil around it. The trees should be wrapped in the fall, before frost danger threatens, and the wrappings removed as soon as the danger period has passed in spring. When the wrapping material is removed, the tree trunk should be given a heavy coat of whitewash to prevent sunburn.

Young potatoes and garden truck are sometimes protected by plowing a furrow between the rows and covering the plants with soil.

Cranberry growers in the marshes of Massachusetts, New Jersey, and Wisconsin flood the marshes with water from large reservoirs when frost is expected. For protection against a light frost it is generally sufficient to raise the level of the water in the ditches. For a moderate frost the water level is raised to the surface of the bog, and when a heavy frost is expected the vines themselves are covered with water. In the first two instances the slight protection required is afforded by the heat given off by the relatively warm water.

DEVICES FOR ADDING MOISTURE TO THE AIR

Smudge fires of damp straw or manure have been used to create a blanket over the area to be protected, the object being to conserve the heat rather than add it to the air. It is possible that such a method may be of some slight benefit when the air is calm and is already nearly saturated with moisture. However, heavy frosts generally occur when the humidity is fairly low and a perfectly calm surface air is seldom met with on cold nights; there is usually at least a slow movement down gently sloping valleys or plains. In a relatively dry atmosphere any moisture thrown off by damp smudge fires will be rapidly lost by circulation and diffusion into the great quantities of air above and surrounding it, and the effect in conserving heat will be very small. Again, if an effective blanket of moisture could be spread over the orchard, a slight breeze would carry it steadily away, to be replaced with cold outside air.

Actual experiments have shown definitely that chemical smoke screens such as those used in military operations, not only afford practically no protection against frost damage but also are considerably more expensive than orchard heating.

Spraying of trees with water to afford protection from frost has been proved to be impracticable. The weight of the heavy coating of ice formed, strips large branches from the trees and sometimes even splits the trunks. (Fig. 5.) The spraying of low-growing plants may be effective if the temperature does not fall too low.

Fairly good results have been obtained by turning warm irrigation water into fields and gardens on moderately cold nights, but this is not satisfactory for protecting orchards during severe frosts. Irrigating an orange grove in California with water having a temperature of 72° F. at the outlet, maintained the air temperature only about 1.5° F. above the outside temperature. The use of cold water would have practically no effect on the air temperature. Frequent irrigation of citrus trees during the winter months may start new growth and render the trees much less resistant to cold.

STIRRING THE AIR

The temperature of the air 40 feet above the ground is often from 7° to 10° F. higher than that 5 feet above. It is obvious that if the air within this distance could be mixed, a damaging frost would not be likely to occur in most cases. A great deal of money has been spent in attempts to do this with large power-driven fans, but up to the present time no practical machines have been built which will afford dependable protection during severe frosts.

ADDING HEAT

The third principle of frost protection is concerned with the addition of heat to the lower air to replace that lost by radiation and con-

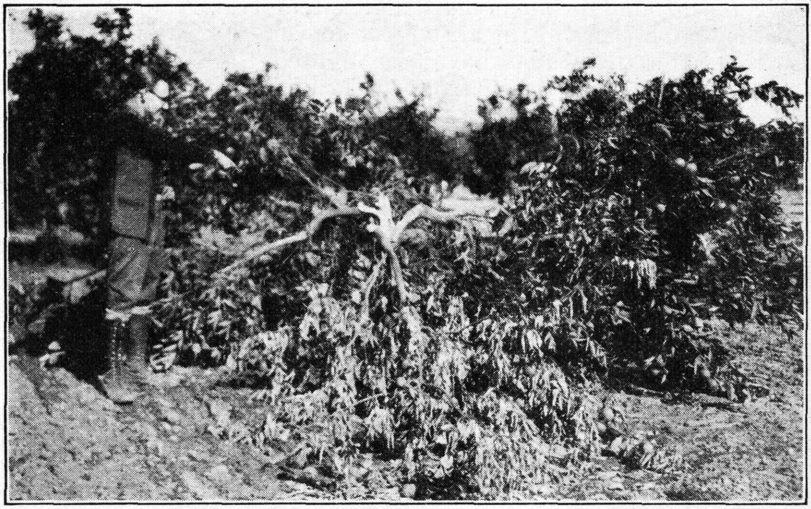


FIG. 5.—Orange tree which was used to determine whether the limbs could carry the weight of ice formed when an overhead sprinkler was operated on a cold night as a means of frost protection. The answer to the question is in the photograph

duction. This is generally accomplished by lighting a large number of small fires throughout the area to be protected.

Persons unfamiliar with temperature conditions in the lower air on frosty nights sometimes speak of the fallacy of attempting to "warm up all out of doors." It is well known that warm air is less dense, and therefore lighter than cold air. This fact is exemplified in many ways in everyday life; the hot gases from a stove or furnace rising through a flue and the lifting power of the old hot-air balloons are good illustrations. As a matter of fact, warmed air continues to rise and cool until it reaches a point where it has the same temperature as the air surrounding it. On first thought, it might be supposed that the air warmed by the fires in orchards or fields would pass upward to a considerable altitude and be replaced by cold air from outside the heated area so rapidly that the effect on the temperature in the heated area would be very slight. However, this is not the case.

FACTORS WHICH INFLUENCE EFFECTIVENESS OF ORCHARD HEATING

On a clear, calm night, as before stated, there is a relatively thin layer of cold air near the ground, with an increase in temperature up to a height of 300 to 800 feet. This condition, known as temperature inversion, makes effective orchard heating possible. The hot gases leave the heaters at a high temperature, but rapidly mix with the surrounding colder air so that the temperature of the whole mass is not very high. This air mass which has been slightly heated does not rise far before it is surrounded by air of the same temperature as itself. When this occurs the upward movement is checked. In other words, the warmer air above the orchard acts as a roof which stops the ascent of the heated air. (Figs. 6 and 7.)

To illustrate with a typical case, let us assume that the air 5 feet above the ground in an orchard has a temperature of 22° F., and that the temperature of the air 40 feet above is 30° F. Let us assume also that after the heaters have been lighted, the temperature of the mass of heated gases rising from the heaters, mixed with the air of

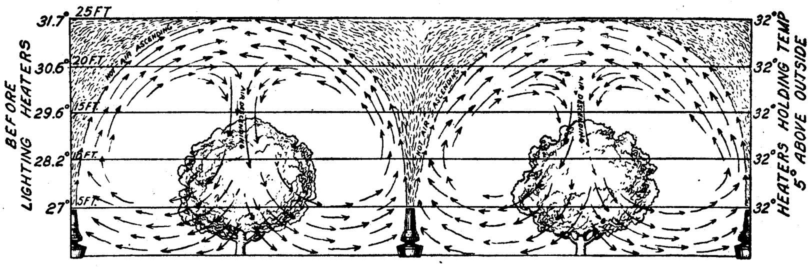


FIG. 6.—Cross section of a row of orchard trees and orchard heaters, illustrating the manner in which temperature inversion makes effective orchard heating possible. This diagram represents air currents and temperature conditions in the orchard on a typical calm, frosty night a few minutes after the heaters had been lighted. Later the shaded area will completely fill the space below the 25-foot level. In this case the thickness of the stratum of air heated is 25 feet, and the temperature rise secured at an elevation of 5 feet above the ground is 5° F.

22° F. temperature in the orchard, is 30° F. This mixture, being 8° F. warmer than the surrounding air, will rise until it reaches a point 40 feet above the ground. Here it comes to a stop, because it is no longer warmer than the surrounding air, which also has a temperature of 30° F. The heaters continue to supply quantities of the mixture of heated gases and air at a temperature of 30° F., which stop rising at lower and lower elevations until the temperature of the air down to the ground has been raised to 30° F. When this has been accomplished, the air temperature in the orchard has been raised 8°, and the temperature inversion has been destroyed; that is, there is no longer any difference in air temperature between the 5-foot and 40-foot levels. Thus, the heat from the burning heaters has been expended in raising the temperature of the air within 40 feet of the ground. (Fig. 7.)

It is plain that the degree of temperature inversion near the ground determines the depth of the layer of air that must be warmed to obtain a definite increase in temperature at the ground. If there is a rapid increase in temperature with increase in elevation, the surface temperature can be raised several degrees more than when the

rate of increase is slight, the amount of fuel consumed being the same in both instances.

The amount of this temperature inversion varies greatly from night to night, and in different localities. It is mainly determined by the amount of fall in temperature from afternoon to early morning. If the afternoon temperature is high and it falls to freezing on the following morning, the inversion is likely to be great, and orchard heating unusually effective. The most difficult nights, when protection is necessary, are those following cold afternoons, when the inversion in temperature is slight.

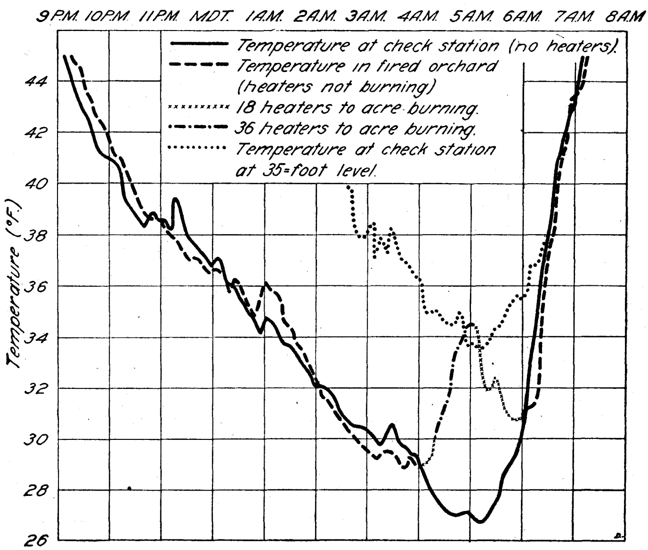


FIG. 7.—Continuous records of the temperature in a pear orchard on a calm, frosty night with considerable temperature inversion, showing the effect of orchard heating. Note that before the heaters were lighted at 4 a. m. the temperature at the check station ran practically the same as that in the orchard equipped with heaters. On this night the stratum of air heated was only about 35 feet in depth, as indicated by the fact that the increase in temperature of 7.5° F. at the 5-foot level in the fired orchard with only thirty-six 5-quart lard-pail oil heaters to the acre burning was unusually large, owing to the strong temperature inversion and lack of air movement

A large number of small fires is more efficient than a small number of large fires, especially in localities where the temperature inversion is relatively slight. The heated gases leave the large fires at a high temperature and tend to rise some distance above the ground, while the gases from a larger number of small fires are mixed with the surrounding cooler air until the temperature of the whole mass near the surface is raised slightly, although remaining still relatively low.

Another and probably the most important factor in protection by heating is the amount of air movement near the ground. When the air is calm, that warmed by the heaters remains over the fired area, and the maximum results in raising the surface temperature are obtained. When the air is in motion, even though it be moving only a few miles per hour, the heat is steadily carried away, and a greater

quantity of fuel must be consumed to obtain the same effect on the surface temperature.

Because of this air drift, which is found on nearly all frosty nights, a large orchard can be protected with less fuel consumption per unit area than a small one, unless heating is practiced generally in the neighborhood. In general, the fuel consumption per acre on an isolated 10-acre orchard will be about double that on a 150-acre orchard, in securing a given rise in temperature on the same night. (Figs. 8 and 9.)

The protection of the border rows of trees in an orchard with an extra line of heaters is important. If no border row of heaters is provided, the air drift will carry the heat from the first two or three rows of fires on the windward side into the orchard, leaving the out-

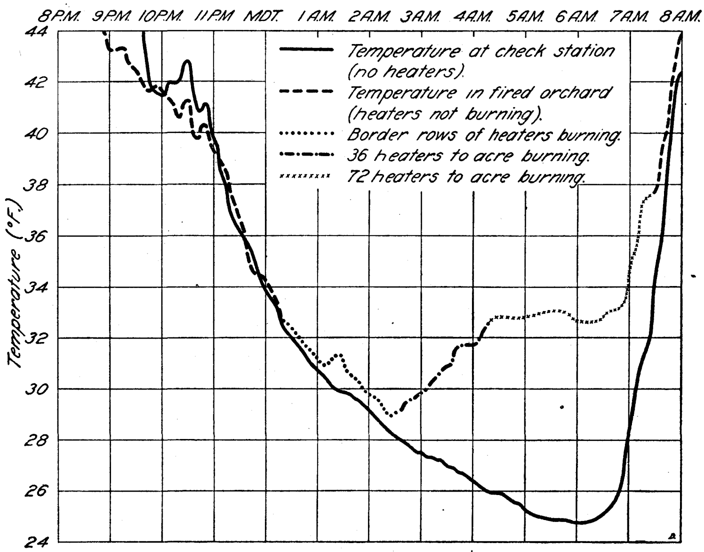


FIG. 8.—Continuous records of the temperature in an isolated 10-acre pear orchard equipped with 5-quart lard-pail oil heaters and at a check station outside. The check-station record indicates what the temperature in the orchard would have been without heating. The temperature was raised 8° F. with 72 heaters to the acre burning. Compare with temperature increase at a larger fired orchard on the same night as shown in Figure 9. Small green apples and pears at the check station were frozen solid on this night

side rows practically unprotected. To secure protection for border trees, a row of heaters, 10 feet apart, should be placed 20 feet to the windward of the outside row. Orchard-heater smoke has very little influence, and the effect of smudge fires of damp straw or manure on the temperature is practically negligible. The belief held by many fruit growers that the smoke "holds the heat down" is without basis.

SMUDGING AND POLLINATION

In some deciduous-fruit districts it has been asserted that the smoke from the open oil heaters interferes with pollination. However, the experience of a large number of fruit growers, who for many years have smudged their trees while in full bloom, does not bear out this

contention. Pollination usually takes place on the day the blossom opens, and even if considerable soot is deposited within the flower on the following night no damage results. As a matter of fact there is seldom enough soot deposited in a blossom to hinder pollination, even when firing is continued for several hours.

Six pear trees, including practically all varieties grown commercially on the Pacific coast, were "smudged" every night during two frost seasons, from the time the buds began to open until the fruit had set, in order to note the effect on pollination. Three open lard-pail heaters were placed almost directly under each tree, and the blossoms were coated with soot to an extent that would never be

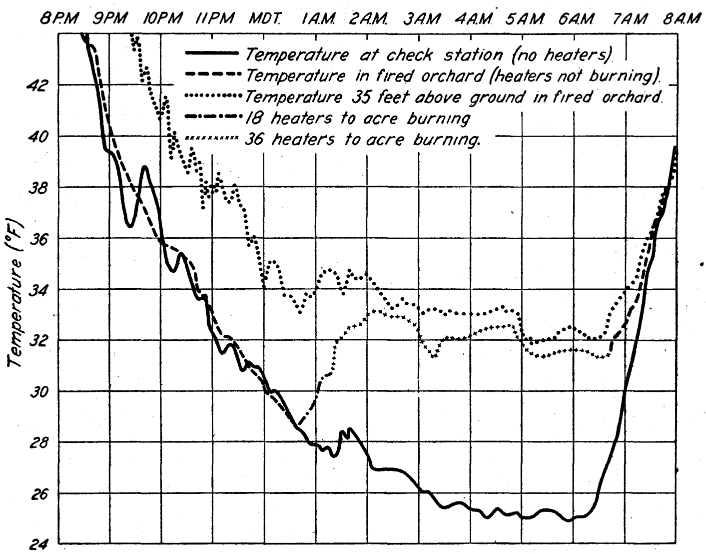


FIG. 9.—Continuous records of the temperature in a 100-acre pear orchard equipped with 5-quart lard-pail oil heaters, and at a check station outside. The check-station record indicates what the temperature in the orchard would have been without heating. The temperature 35 feet above the ground in the orchard equipped with heaters is shown by the dotted line. There was only about half as much temperature inversion on this night before the heaters were lighted as in the record shown in Figure 7. The temperature was raised 7° F. at this location, burning only 36 heaters to the acre. No heaters were lighted at any time during the night in the row in which the temperature station was located. Reserve heaters had to be lighted twice during the night to replace those which were burning dry. The fall in temperature about 3 a. m. and again at 5 a. m. was due to heaters burning low

found in actual heating practice. All the smudged trees bore heavy crops both years, and the yield of near-by trees that were not smudged was not noticeably larger. (Fig. 10.)

Statements that bees will not work in blossoms that have been smudged may be due to a lack of understanding of the habits of the bee. It is well known that bees often will not work on even moderately cool days; if the afternoon temperature is below about 60° F., the bees may remain in the hive. On days following the occurrence of a frost heavy enough to make smudge protection necessary the temperature is likely to be sufficiently low to keep the bees from working to any great extent. On warm, sunshiny days following heavy

FIG. 10.—Fine crop of perfectly shaped Bartlett pears on a tree used in experiments to determine the effect of smudging on pollination. This tree was smudged heavily every night from the time the buds began to open until the fruit had set. Photograph taken soon after spraying

frosts, the writer has often observed great numbers of bees working in the blossoms that had been heavily smudged on the previous night.

The smoke from open heaters is very dense, and in some localities the residents of towns have objected to orchard heating on account of the resulting dirt. The smoke problem has been partially solved by the development of improved heaters, but no practical heater has yet been devised that will burn under orchard conditions without giving off some smoke. In communities where fruit growing is one of the important sources of income, the general public has almost as vital an interest in frost protection as the fruit grower himself. Most of the gross return for the fruit crop, excepting freight charges, is spent in the section where the fruit is grown. When the size of the crop is materially reduced, the loss is felt, directly or indirectly, by nearly everyone in the community. In some sections where smoke from orchard heating operations causes inconvenience, it is the realization of the community interest that prevents undue criticism of the efforts of the grower to save his crop.

PROTECTION OF OLIVES

In some parts of California the olive crop is often damaged severely by fall frosts when the fruit is being picked. In a few olive-growing communities as much as 70 per cent of the crop has been lost in some seasons in this manner. The experience of olive growers who have protected their crops during fall frosts has shown that orchard heating for mature olives is entirely practicable and that the flavor of the fruit is not affected by the smoke or fumes from the burning oil.

ORCHARD-HEATER FUELS

The primary consideration in orchard heating is to supply sufficient heat to offset the natural cooling through radiation of heat to the sky, and to raise, to above the danger point, the temperature of the cold air drifting into the orchard. From a theoretical standpoint, it does not matter particularly what fuel is burned, provided sufficient heat units are supplied to maintain a safe temperature and the heat is properly distributed throughout the orchard. Many different grades of oil have been used in orchard heating, from the heavy crude oil as it comes from the wells, to refuse cylinder oil drained from automobile motors. Coal, coal briquets, wood, oil-saturated wood shavings, tree prunings, baled straw, carbon briquets (a by-product of the manufacture of illuminating gas from crude oil), a mixture of coal dust, asphaltum, sawdust, and niter, and even discarded automobile tires, have been used as orchard-heater fuels. The use of many of these fuels is extremely limited, owing to the small supply available. Others are eliminated from serious consideration because of their cost. Next to availability and cost, the amount of labor involved in protecting an orchard successfully probably has had more influence than any other one factor in limiting the number of orchard-heater fuels for general use. At the present time oil is an overwhelming favorite as a fuel for frost protection. Carbon briquets and coal briquets are used to a limited extent in the citrus districts of California, and a considerable proportion of the orchard heaters in use in the State of Washington burn coal briquets.

The use of wood for orchard heating has been abandoned almost entirely, on account of the great amount of labor involved.

Experience has shown that if the proper grade of oil is used, this fuel involves the least amount of labor. On the other hand, briquets have certain advantages over oil, particularly for protecting small acreages. Briquets are easily handled and stored, and eliminate the necessity for having storage and distributing tanks. Disadvantages of briquets as compared with oil are the following: After they have been lighted it is difficult or impossible to extinguish them, in case the temperature rises. The lowest temperature usually occurs about sunrise, so that the heaters must be delivering their maximum amount of heat at that time, making a loss of fuel almost unavoidable. The heaters must be refueled at frequent intervals in order to maintain a safe and fairly even temperature in the orchard. When coal briquets are burned the ashes must be shaken from the heaters frequently to prevent the smothering of the fire, particularly if it is necessary to continue the firing over a long period. However, if briquet heaters are properly handled and a sufficient number to the acre are used, they are as dependable as the oil heaters in maintaining a safe temperature.

Carbon briquets make an extremely hot fire and leave very little ash, but the supply of this fuel is very limited. They are more difficult to light than coal briquets and have caused some difficulty in burning out heater grates. Briquet heaters burn with very little smoke after the first few minutes of burning, but sulphur fumes are sometimes given off in quantities large enough to be objectionable.

Coal-burning orchard heaters were used in southern California for many years but have gone out of use almost entirely during recent years. Objections to coal heaters are based on the large amount of labor required to fill, light, and refuel them, and to the fact that the irregular size and shape of the individual lumps of coal cause a lack of uniformity in the rate at which the heaters burn. In filling the heaters large lumps of coal may lodge in such a position as to leave open spaces underneath. Some heaters will then burn out with a rush, while others will smoulder for hours. The principal advantage in the use of briquets over coal for orchard heating lies in their uniform size and shape.

Petroleum coke, a residue composed of almost pure carbon, obtained in gasoline "cracking" plants, is an excellent fuel for use in solid-fuel heaters. It creates a hot fire and leaves very little ash.

Coal coke is unsatisfactory as an orchard-heater fuel. It is difficult to light and the fire is almost smothered by ashes soon after it is lighted.

Electric power as a source of heat for protection from frost is entirely impracticable because of the large amount of electricity required to protect even a small orchard.

The gravity of orchard-heater oil is of minor importance, so long as the asphaltum and water contents are reduced to a minimum. An excess of water in the oil will cause the heater to boil over or explode, while an excessive amount of asphaltum will fill the heaters with a hard, sticky mass, very difficult to remove. In purchasing oil for orchard heating, the grower should specify the lowest asphaltum content obtainable, and in no case should oil containing in excess of

3 per cent asphaltum by distillation test be accepted. In cases where it is not possible to obtain the asphaltum content by analysis, a sample of the oil should be secured and burned in an orchard heater. The proper type of oil should leave only a small amount of dry, cindery residue in the bottom of the heater after it has been burned dry five times. Practically all of the larger oil corporations are now able to furnish an excellent orchard-heater oil, from 28° to 36° B., containing practically no water or asphaltum. The lighter oils burn somewhat faster and contain slightly fewer heat units per gallon, but the difference is too small to be of much consequence.

OIL HEATERS

Up to the present time few deciduous-fruit crops have been valuable enough to warrant the use of any but the simplest and cheapest types of heaters, such as the lard-pail type, for protection against frost. Since good results can be obtained with the lard-pail heaters when a sufficient number to the acre are used, the only incentive to change to a more complicated type of heater is the abatement of the smoke and soot. The indications are that the smudge does not injure deciduous blossoms or fruit, and its elimination is desirable only on account of the resulting dirt.

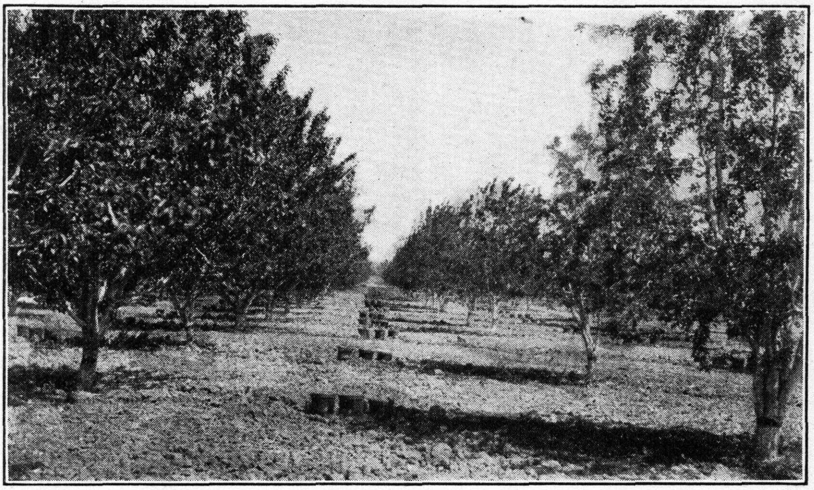


FIG. 11.—Ten-quart lard-pail oil heaters set three to a tree in a pear orchard. Only one heater of a set is ever lighted at one time; the others are held in reserve, to be lighted as needed, when the firing period is unusually long

The lard-pail heaters are not well suited for the protection of citrus fruits because (1) at the time protection is necessary the fruit is almost ready to be picked, and a deposit of oily soot is likely to impair its marketing qualities, and (2) protection is necessary in midwinter, when the temperature is likely to remain below the danger point continuously for 10 or 12 hours, and heaters of large capacity and long-burning time are required.

In deciduous-fruit districts where orchard heating has been practiced for a long time many growers prefer the 5-quart lard-pail

heaters on account of the excellent distribution of heat throughout the orchard which their use permits. This is carrying out the idea of the superiority of a large number of small fires over a small number of large fires. When these small heaters are used the temperature can be raised 1° or 2° when a light frost occurs without wasting fuel. The burning time of the open 5-quart and 10-quart lard-pail heaters is the same, about three to three and one-half hours, depending on the gravity of the oil and the air movement, as the burning surface in the 10-quart heater is double that of the 5-quart size. The open 10-quart heater burns twice as much oil as the 5-quart, and furnishes twice as much heat in a given time, but when the 5-quart heater is used the distribution of heat is better.

Sheet-iron disks, placed over the top of the lard-pail heaters and partially covering them, supported by metal fingers which clamp lightly over the rims of the heaters, known as spiders or soot

FIG. 12.—Five-quart lard-pail oil heaters burning at daybreak. The set first lighted has burned dry and the second lighting is burning low

arresters, have the effect of doubling the burning time and reducing the amount of heat produced in a given time by one-half. (See figs. 13 and 15.) The use of the spiders with oil containing more than 3 per cent asphaltum is inadvisable, as the accumulation of soot underneath them may completely smother the fire. With the better grades of oil they are very satisfactory. The 10-quart heaters with the spiders in place produce as much heat in a given period of time as the 5-quart heaters without spiders. If it becomes necessary to combat a sudden drop in temperature, the spiders can be flipped off quickly with a stick, and the amount of heat produced thus doubled.

The number of lard-pail heaters necessary for adequate protection varies with the location of the orchard, but in no case should there be fewer than 150 to the acre. The number should be the same, whether the 5-quart or the 10-quart heaters are used. A favored installation in deciduous orchards is one 5-quart and one 10-quart heater per tree.

The 5-quart heaters are then used for light frosts of short duration, the 10-quart heaters being reserved for the colder nights with long firing periods when the 5-quart heaters alone will not maintain a safe temperature throughout the danger period. In the coldest orchards the heater installation is often 200 to the acre. All of the heaters are never burned at one time; most of them are held in reserve on account of their short burning period. Occasionally, when the temperature reaches the danger point by 11 p. m., it may be necessary to make three lightings to replace heaters which have burned dry. (Figs. 9 and 11.)

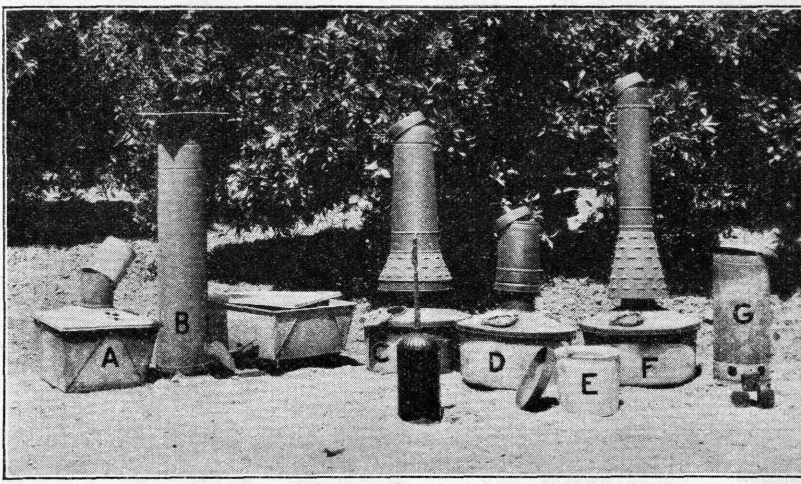


FIG. 13.—Types of orchard heaters in general use. Left to right: A, Short-stack oil heater; B, drip-feed oil heater with separate fuel reservoir; C, jumbo-cone high-stack oil heater. Here the draft hole at the left has been uncovered and the heater is ready to be filled with oil. After filling, the draft cover is slipped back into place. A flame burning on the surface of the oil in the reservoir turns some of the oil into gas, which burns in the cone and in the stack. (See fig. 14.) Air to support the combustion in the cone and stack is admitted through the louvers in the cone; D, double-stack oil heater, with draft opening closed. The operation of this heater is similar to that of the jumbo-cone type, except that the oil gas burns in the short stack and in a flame which extends a foot or more from the top of the stack. The air to support the combustion in the inner stack is warmed by passing it between the inner and outer stacks; E, 10-quart lard-pail oil heater, with spider in place; F, baby-cone high-stack oil heater. This type is similar in principle to the jumbo cone just described; G, solid-fuel heater, burning coal or carbon briquets, coal, or petroleum coke; three carbon briquets are shown in front. In the center foreground is a lighting torch used for lighting oil heaters

When the large-capacity heaters, equipped with drafts and stacks, are used in deciduous orchards, from 35 to 50 to the acre, depending on the heater used, will give adequate protection. Their fuel capacity is sufficient to carry through the longest cold nights without refueling, and no reserve heaters are necessary. By regulating the drafts the rate of burning can be increased or decreased according to necessity. (Fig. 25.)

Citrus groves should be equipped with heaters having a capacity of at least 9 gallons of oil. A great many types of large-capacity oil heaters have been developed, but only three or four are in general use. All of the improved types use either the "down-draft" or the "drip-feed" principle. In the down-draft heaters, air is admitted through the top of the oil reservoir, causing combustion to take place

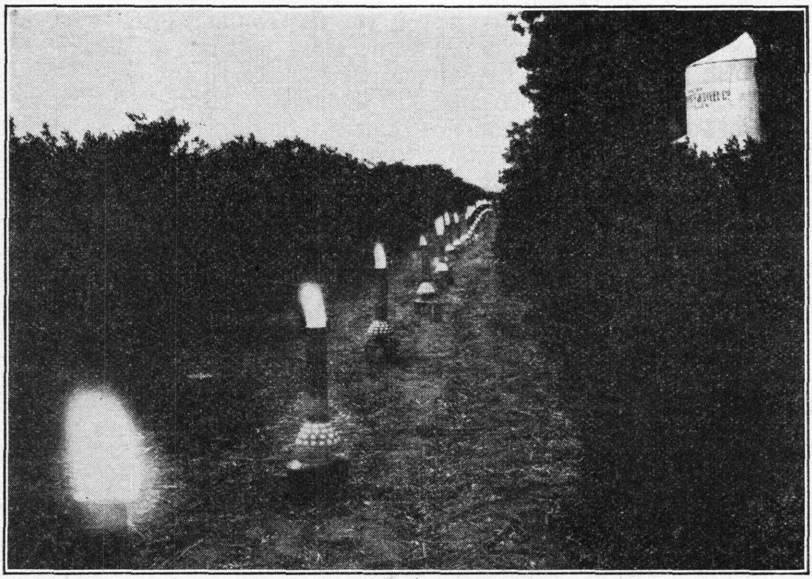


FIG. 14.—Jumbo-cone oil heaters burning at night at a rather high rate

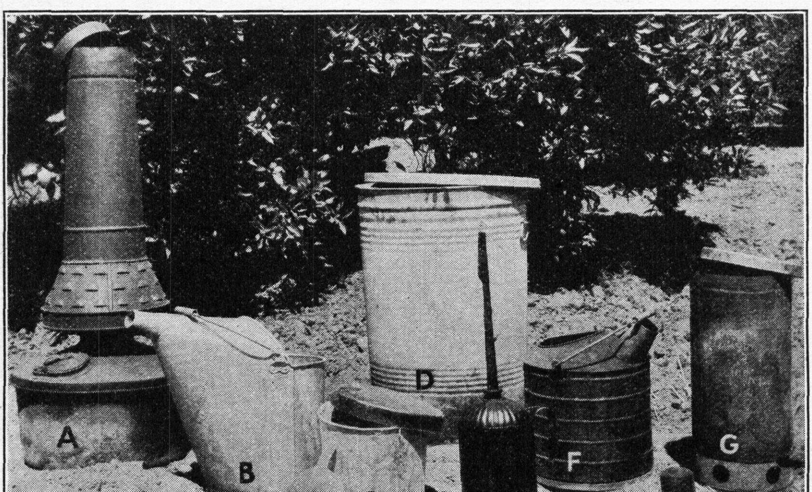


FIG. 15.—A, Jumbo-cone orchard heater; B, bucket for filling oil heater; C, 10-quart lard-pail oil heater, with spider; D, type of reservoir sometimes used to store oil in the orchard so that it will be accessible for rapid refilling of the heaters; E, torch for lighting; F, another type of bucket for filling oil heaters; G, solid-fuel heater, with carbon briquets in the foreground

on the surface of the oil and raising the temperature sufficiently to change some of the oil to gas. The hot gas is then burned as it passes upward through the stack. Air to complete the combustion is admitted through perforations in the stack near its base. In one type of short-stack heater, much of the smoke is eliminated through heating the air before it passes through the perforations into the stack, by admitting it through a space between the stack and an outer metal shell. In the drip-feed heater the oil is fed from a separate reservoir through a small pipe to the burner, which is set at the base of the stack. Drip-feed heaters require a very light oil, practically free from asphaltum. (Fig. 13.)

When burning at a normal rate, the larger heaters consume about one-half gallon of oil per hour, but their oil consumption can be more than doubled by increasing the draft opening. Generally speaking, the high-stack heaters, when properly regulated, burn with less smoke and soot than any other type in general use. These were formerly

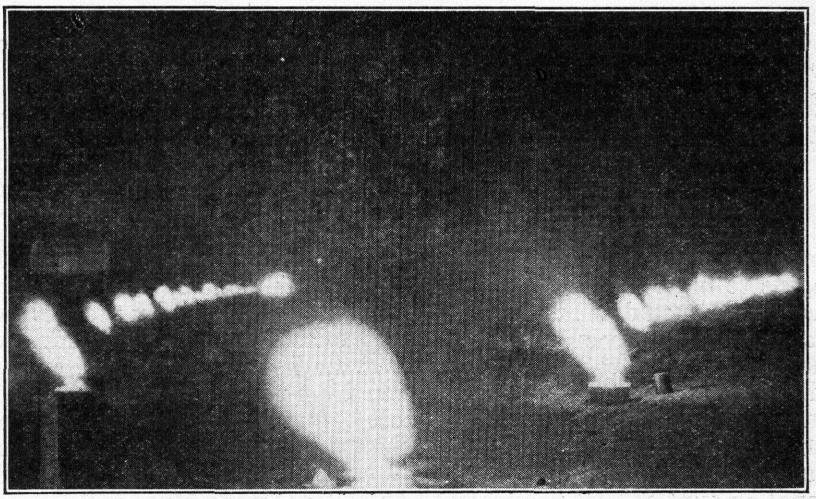


FIG. 16.—Short-stack oil heaters burning in orange grove at night

open to the objections that the heat was released too far above the ground, at too high a temperature, and with too great an upward velocity, to obtain the best results. Recent improvements in design have largely overcome these objections, and the latest types give excellent results under almost any conditions. The stack has been shortened and its diameter increased, while combustion has been concentrated to a great extent in a chamber or "cone" directly above the heater bowl.

Although the smoke and soot are more or less completely consumed in the high-stack type, the lard-pail heaters are practically as efficient as those with high stacks, and are fully as satisfactory in raising the temperature with a given amount of fuel. Both heaters make available practically all the heat units in the oil.

The lard-pail or other open oil heater should never be used for the protection of citrus trees, because of the soot deposited on the fruit. Citrus groves, for adequate protection, should be equipped with 50

of the 9-gallon high-stack heaters, or from 50 to 100 of the low-stack heaters to the acre.

The use of small oil heaters which burn slowly, set directly under the trees, is impracticable. It has not been possible to distribute the heat uniformly through the trees, and when the heaters are burned under citrus trees, there is danger of serious tree injury if the heaters burn too high.

SOLID FUEL HEATERS

Orchard heaters burning solid fuels should be set in deciduous orchards at the rate of 80 to 100 to the acre, and in citrus orchards at the rate of 100 to 125 to the acre. Briquet heaters are loaded in a great many different ways in different sections. The most common method of fueling in the deciduous-fruit districts is to place 17 briquets in the bottom of the heater, add a handful of dry pine kindling, split fine, and then 9 more briquets above the kindling. A slightly heavier fuel charge is used in the citrus districts, usually about 30 briquets to the heater.

Coal-briquet heaters deliver their maximum amount of heat about 20 minutes after being lighted, and after two to two and one-half hours of burning the intensity of the fire is considerably reduced. Starting with the original charge of 26 briquets, the heater should be refueled with a charge of 8 not later than the second hour of burning. A refuel charge of 8 briquets should be added at the end of each additional hour of operation, as long as the heaters are burned. If the initial refueling is delayed until the end of the third hour, the new charge is likely to smoulder and smoke for some time before it begins to burn properly. The addition of cold, damp fuel to a fire that has burned down to a bed of glowing lumps, actually reduces the amount of heat given off by the heater for some time afterward. At the time of each refueling, the top of the heater should be grasped with gloved hands and the ash cleared from the fire by shaking. An extra refueling is often necessary just before sunrise, to take care of the sudden drop in temperature that usually occurs at that time. Usually a new charge of from 4 to 6 briquets will furnish the additional amount of heat necessary to offset this temperature fall.

Several different types of briquet heaters are in use in the citrus districts, in some of which the fuel is ignited at the top, the fire working slowly downward. This gives a longer burning period and a somewhat more even heat.

Carbon briquets burn more slowly and longer than the coal briquets and maintain a more even temperature in the orchard. They are usually lighted from the top, as the grates are likely to be damaged when the fuel is lighted at the base. When using solid-fuel heaters burning carbon briquets or petroleum coke equipped with draft openings at the base, care should be taken to avoid opening the drafts too wide, as both heaters and grates may be badly damaged with too hot a fire.

DIRECT RADIATION FROM HEATERS

All orchard heaters radiate a part of the heat produced in the combustion of the fuel. The higher the temperature at which the heater

operates, the greater will be the proportion of the total heat produced which will be given off in the form of radiation.

Part of the heat radiated by an orchard heater is lost directly to the sky, without appreciable effect on the temperature of the air or of the plants. Radiant heat travels in straight lines and is completely absorbed or reflected by fruit, leaves, or ground, which may intercept it. Considerable indirect warming of the air takes place through contact with surfaces which have been warmed by radiation from the heater. During the progress of cold waves, or freezes, when temperatures below the danger point are accompanied by wind, radiation from the heaters to the trees may be of considerable importance in preventing damage. In the protection of low-growing crops, such as potatoes, strawberries, or cranberries, the radiated heat plays an important part in maintaining a safe temperature.

DISTRIBUTION OF HEATERS

For the best distribution of heat throughout an orchard it is better to have the heaters placed in every row, if possible, instead of concentrating them in alternate rows. This makes for a more general intermixing of the warmed air with the surrounding cold air. In orchards located on gentle slopes or in other places where there is a steady air drift during cold nights, the large-capacity heaters can be concentrated in alternate rows, at right angles to the direction of the wind. The air movement will take care of the distribution of the heat throughout the orchard. However, the failure of the air drift during a freeze may cause considerable damage in rows without heaters.

The heated air from a fired orchard often drifts through the adjoining portions of neighboring orchards not fired, affording them in some cases even more protection than the fired orchard itself.

FILLING HEATERS

Some growers who protect 5 acres or less with oil fill the heaters from metal drums of about 50-gallon capacity. A wagon tank is more satisfactory in most cases and is almost a necessity where more than 5 acres are protected. Three men with a wagon tank can fill heaters very rapidly, one man driving and two men filling. (Fig. 17.) The oil is drawn into 5-gallon buckets with lip and spout, and two to four rows of heaters are filled on each trip. (Fig. 15.) Some growers use heavy rubber hose for filling the heaters directly from the wagon tank. Two lines of hose are attached to the tank outlet, and one or two rows of heaters on each side of the tank wagon are filled on each trip. This method eliminates carrying the oil from the tank to the heaters. Great care should be taken not to injure the tree roots by spilling oil in the orchard. Stack heaters should be filled to about 1 inch below the top of the bowl. A greater amount of fuel makes lighting difficult.

A great many methods of filling the briquet heaters are in use. Probably the most efficient and the one involving the least labor is to load the fuel on light wagons for hauling through the orchard. A large funnel, with its mouth slightly smaller in diameter than the top of the heater, is placed therein, and the fuel charge is poured

from a shovel built to hold the correct quantity of fuel. In this way the fuel is lifted down from the wagon instead of being lifted up from the ground. Reserve fuel for refueling at night is kept in boxes placed beside each heater. Reserve fuel should never be stored on the ground, as weeds or other plants may grow over it and make it difficult to find at night. The reserve-fuel box should be placed not nearer than 18 inches from the heater to prevent its taking fire.

LIGHTING HEATERS

All types of heaters are lighted through the use of a special lighting torch, burning a mixture of gasoline and kerosene, in equal proportions. (Figs. 12 and 15.) The torch is made in the shape of an ordinary oil can, but larger, with a capacity of from 1 to 2 gallons.

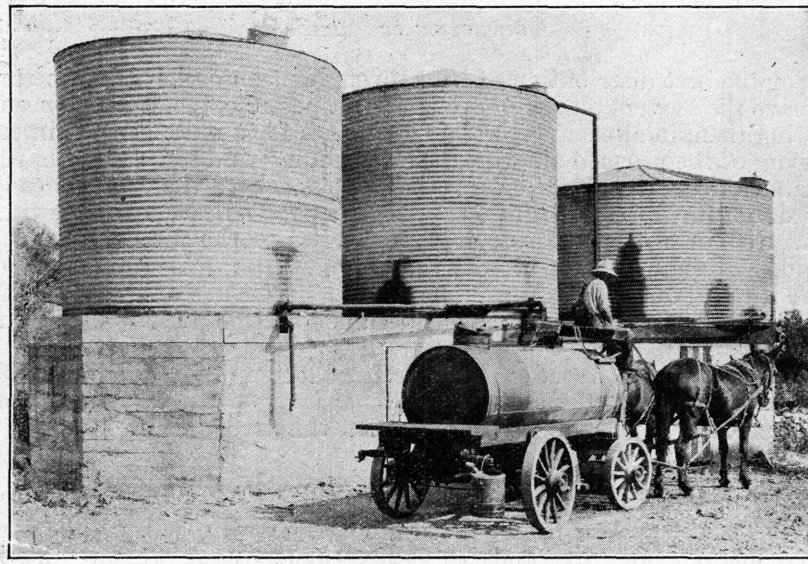


FIG. 17.—Orchard oil-storage tanks and tank wagon used for hauling oil and filling heaters

The diameter of the spout is large enough to allow a small stream of the lighting fluid to pass through when the torch is inverted. At the end of the spout is an asbestos wick, which carries the flame. As the lighting fluid passes the wick it is ignited, and a stream of burning liquid is poured into the heater.

If these torches are correctly designed and constructed and reasonable precautions are taken in handling them, there should be no danger connected with their use. A small-mesh metal screen is soldered over the base of the spout, to prevent the ignition of gases in the fuel reservoir. (Fig. 18.) With the screen properly attached, slight explosions of the gases in the spout may occur without danger, as the flame will not pass through the screen. The screen should be examined at the beginning of each frost season, to make sure it is intact and firmly soldered to the rim of the spout. The diameter of the spout should be as small as possible and still allow an adequate

flow of lighting fluid. A large spout may contain sufficient explosive gas to blow out the screen and ignite the gas in the reservoir, causing a serious explosion. In the latest torches the air to replace the lighting fluid poured out of the spout is taken into the reservoir through a very small pipe soldered into the back portion of the top of the reservoir and extending the full length of the torch handle. In earlier designs, the air passed back through the spout, interfering with the flow of lighting fluid and tending to carry the flame back into the spout, and increasing the danger of explosion.

FIG. 18.—Lighting torch which exploded during use, showing perforation in safety screen at base of spout, which allowed flame to reach explosive gases in reservoir

Care should be taken to see that the torch spout is screwed down firmly, so that there will be no leakage at the connection. It is advisable to have about an inch of wicking extending beyond the end of the spout, as there is a tendency for the fire to jump back into the spout when a short wick is used. In carrying torches through the orchard the spout should be uppermost. If the torch is carried in an inverted position, the flame from the wick heats the spout to a high temperature, which increases the danger of explosion. It has been found through long experience that a mixture of equal portions of gasoline and kerosene makes the best lighting fluid. When pure gasoline is used the danger of explosion is greatly increased, and the fluid lacks body to carry the flame to the surface of the oil. The lighting mixture should be made up fresh each frost season. Several instances are on record of growers who carried over a supply of lighting fluid through the summer months, and during the hot days of summer most of the gasoline evaporated, leaving only the kerosene. When the time for lighting the heaters arrived, the torches refused to burn, and much of the crop was lost before gasoline could be secured and a new lot of lighting fluid prepared. If the lighting mixture is made up in large quantities and left standing in drums, as is often done on large orchards, the liquid should be thoroughly mixed by stirring or shaking before it is drawn off into the torches.

New heaters are usually difficult to light the first time. To light new lard-pail heaters the lighting fluid should be poured in a ring

around the inside rim, so that the flame will burn on the inside walls of the heater. After they have once been burned dry, the soot adhering to the sides will act as a wick, and the heaters can be lighted very rapidly.

The larger heaters, with stacks and drafts, should be wicked before being lighted the first time. Any one of a number of materials can be used for wicking. Wisps of excelsior, small rolls of newspaper, or short lengths of hemp rope are the materials most commonly used. The wicking material should be loosely inserted in the draft hole of the heater, taking care not to choke the draft. After the heaters have been burned for an hour or more, they can be lighted easily and rapidly without wicks.

Most types of high-stack heaters must be burned at a high rate when first lighted, until the oil and the heater have been thoroughly warmed, or they may fail to burn. The usual practice is to open the drafts wide for lighting, regulating the rate of burning about five minutes later. The drafts should be adjusted from time to time during the night as the oil gets lower in the reservoir, to maintain a clean flame and to prevent overheating the stack, which results in an unduly high depreciation.

In placing stack heaters in the orchard, the draft openings should be faced uniformly in one direction for easier lighting and regulating.

One lighting torch should be kept on hand for each 5 acres, with one or more additional to care for emergencies.

When lard-pail heaters are used in deciduous-fruit orchards, the usual procedure is to light the windward border rows and alternate heaters in every fourth row when the temperature approaches the danger point. When the fall in temperature is unusually rapid, alternate heaters in alternate rows are lighted. After the initial lighting has been completed, the effect on the temperature is noted and decision is made as to whether additional fires are necessary. Throughout the night only enough heaters are lighted to maintain the temperature above the danger point. As soon as a row of heaters begins to burn low, reserve heaters should be lighted, as the amount of heat given off during the last half-hour of burning is small.

In extinguishing lard-pail heaters, the covers should be placed upside down to indicate the heaters in need of refilling the next day.

Where the larger capacity stack heaters are used in deciduous orchards the usual initial lighting is one-fourth to one-half the heaters, depending on how rapidly the temperature is falling. The amount of heat given off by these can be regulated by increasing or decreasing the draft opening.

In citrus orchards the initial lighting of the stack-oil heaters includes nearly always one-half or all of the heaters in the grove, the temperature increase being regulated through the manipulation of the drafts.

Briquet heaters are lighted with a torch similar to that used for lighting oil heaters, but having a larger lighting fluid capacity. Paraffin-soaked balls of tow, dried peach pits, carbon or wood-shavings briquets soaked in oil, and oil-soaked wood shavings, are some of the materials used, in addition to kindling wood, for lighting the briquet heaters in the citrus districts.

Under competent supervision, high-school students and students in the higher grades in grammar school furnish an excellent and dependable supply of labor for lighting heaters. One man should be able to light heaters on a minimum of 5 acres.

STORAGE OF FUEL

In order to handle orchard heating successfully, it is necessary to have sufficient fuel within reach to last through the longest cold spell likely to be experienced. In too many instances the crop has been protected successfully through several cold nights at considerable expense, only to be lost on the last night of a freeze because of lack of fuel. Where orchard heating is practiced by many growers in a community it is a good plan to buy and store large quantities of fuel oil on a cooperative basis, as is done in southern California. (Fig. 19.) The heaters in orchards located in the immediate vicinity of

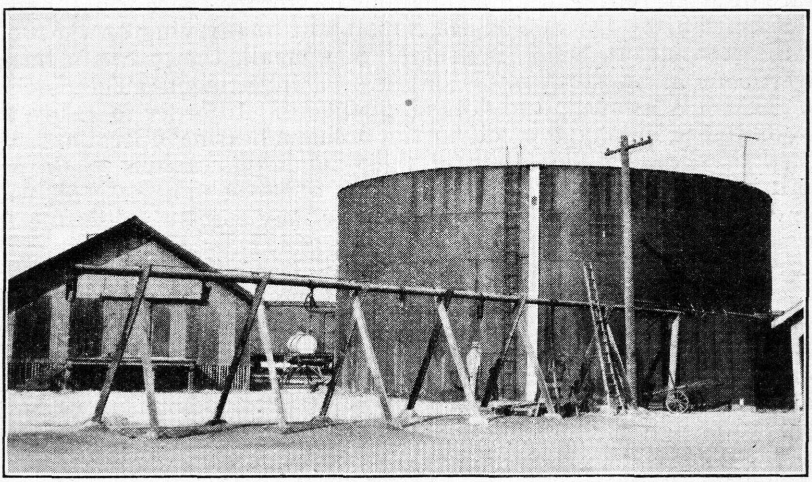


FIG. 19.—Community oil-storage tank of 450,000 gallons capacity in southern California

the community storage tanks can be filled by hauling oil directly from these tanks, but individually-owned storage tanks should be installed in every fired orchard located more than a half mile from the community tanks.

The amount of oil stored at the orchard should be equal to at least three times the capacity of all the heaters. If possible, orchard storage tanks should be arranged so that they can be filled and emptied by gravity. If it is not possible to do this, they should be elevated, so that the wagon tanks can be filled by gravity. (Fig. 17.) It is better to pump oil into the tanks than to pump it out, as the failure of a pump used to lift oil from an underground tank may cause the loss of a crop. During recent years corrugated galvanized sheet-iron tanks have been installed almost exclusively for orchard storage in southern California. The use of corrugated iron makes it possible to use a lighter weight iron without reducing the strength of the

tank. Concrete oil-storage tanks have been unsatisfactory in most cases because of leakage.

In the citrus districts of California the erection of cooperative oil-storage tanks is usually handled by the local packing-house unit of a cooperative-marketing organization, the cost being borne collectively by all the growers affiliated with the local unit, whether they practice orchard heating or not. Growers who do not protect their groves feel that they may desire to equip them later, or that the stabilizing of the operations of their organization is of sufficient importance to warrant their cooperation.

In some districts in California, however, the cost of these community tanks is borne entirely by the growers who protect their orchards, and in such cases it is necessary to form a separate nonprofit cooperative corporation under the laws of the State. The par value of each share of stock is dependent on the amount of storage per share which the owner is allowed in the community tank. A share of stock representing 500 gallons of storage space usually costs from $8 to $10. Outside of the annual cost of carrying on the work of the association, which is usually very small, the grower's initial investment in his stock is his last capital investment. The association acts only as agent and does no financing. In order to insure the use of the proper type of oil in the orchard-heating operations, the board of directors reserves the right to determine the grade and quality of the oil to be stored. Shares of stock may be sold, with the directors' approval, so that a grower may receive full value for his stock in case he sells his grove.

Provision should always be made for cleaning oil-storage tanks, especially if the heaters are emptied into the tanks at the end of the season. The soot and sludge remaining in the heaters after they have been burned several times gathers in the lower portion of the storage tanks and, if not removed at frequent intervals, soon materially reduces the effective storage capacity. Care should be taken to keep storage-tank covers water-tight to prevent leakage of water into the oil.

Briquets or other solid fuels for orchard heating are usually carried by local dealers, but it is well for the fruit grower to carry on his own property sufficient fuel for three nights of firing. Reserve fuel is often piled in the open, but it will be found much more satisfactory to store it in bins under cover.

CARE OF OIL HEATERS

The amount of attention given to storage and care of oil heaters varies greatly in different parts of the country. In parts of California where the annual rainfall is light, many fruit growers leave the heaters in the orchards during the entire year, setting them up close to the trunks of the trees after the danger of frost is past. Trees are sometimes injured or even killed through oil from leaky heaters penetrating the soil around the roots. For this reason, heaters left in the orchard should be emptied at the end of the season. Lard-pail heaters are usually covered with a film of oil, which helps to prevent rusting, and the rate of deterioration in the orchard is little, if any, greater than is the case when they are stored under

cover. Where there is considerable annual rainfall, lard-pail heaters should be emptied, dipped in heavy oil, and stored under cover when not in use. With ordinary care heaters of this type will last 10

FIG. 20.—Three types of tongs for moving lard-pail orchard heaters while full of oil, during cultivation or spraying operations. Larger tongs are made for moving the 9-gallon heaters used in the citrus districts

years or longer. They have been used 14 and even 16 years without the loss of more than a small percentage through deterioration. Some growers prevent contact with the ground by placing the heaters on small wooden platforms.

The owners of many of the larger orchards using the stack heaters believe it pays well to give them a thorough overhauling every two years. They are disassembled and hauled to a central point, and after the old coat of paint and heater oil have been burned off, care being taken not to damage the metal by overheating, the bowls are brushed thoroughly with a steel brush to remove rust and dirt and are examined for leaks. They are then heated on an iron grating over a fire, and a good grade of stack paint is applied hot. Some growers coat the bottom of the heater bowl by floating it on a reservoir of very hot asphaltum, using stack paint to cover the rest of the heater. The mixture of soot and asphaltum in the bottom of the heater at the end of the firing season makes excellent fuel for heating the bowls.

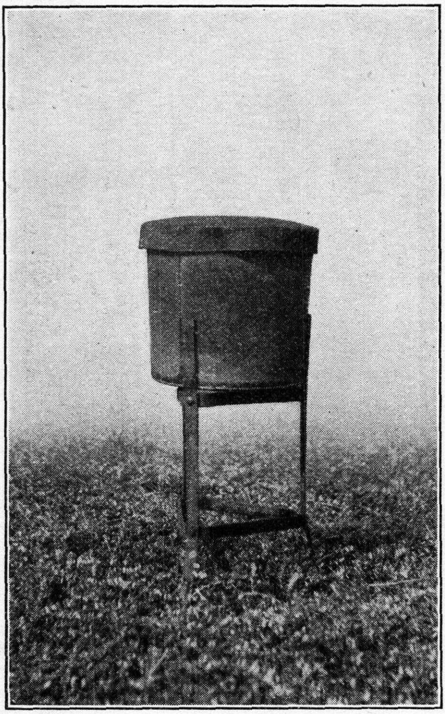


FIG. 21.—Lard-pail heater on tripod for protection of low-growing crops

PROTECTION OF LOW-GROWING CROPS BY HEATING

The protection of strawberries, cranberries, and truck crops from frost damage through the use of orchard heaters is entirely practicable, but only crops which bring a relatively high return will justify the expense. Winter-grown potatoes have been protected in this manner in California for many years. In a ½-acre plot of cranberries in western Washington, equipped with forty 10-quart lard-pail oil heaters placed on iron tripods so that their tops were 2½ feet above the ground, to avoid burning the vines, the temperature at the surface of the vines was raised an average of 5.1° F., with a maximum increase in temperature of 6.6° F. The heaters were burned with the spiders in place, which reduced the rate of burning about one-half. If a larger area had been heated, the rise in temperature secured undoubtedly would have been considerably greater. (Figs. 21 and 22.)

During the spring of 1927 a Clark Seedling strawberry bed in eastern Washington, about 1 acre in size, was equipped with double-stack oil heaters, placed 20 feet apart, or at the rate of 100 to the acre. These also were mounted on iron tripods, which raised the tops of the heater stacks to a height of 30 inches above the ground. (Fig. 23.) Although the severest spring freeze in more than 40 years occurred on the night of April 19, when the strawberry vines were about 20 per cent in full bloom, practically a full crop of berries was harvested during the season. The temperature at the check

station adjoining the plot fell to 19° F., and was below 32° F. for more than nine consecutive hours. The average increase in temperature at the surface of the vines due to the heating was 8.4° F. and the maximum increase was 12.1° F., at a point 14 feet from the nearest heater. Owing to the long burning time the heaters had to be refueled during the night and a few burned dry before the temperature reached its lowest point. The operating costs of protecting the plot on three cold nights, including the freeze night already mentioned, totalled $111.66. The overhead expenses for the season were $46.54, making the total expense $158.20. If larger-capacity heaters had been used, which would have eliminated the cost of refueling during the night, the operating expenses would have been reduced by about 6 per cent.

This experiment was continued during the spring of 1928, a slightly different type of heater being used. Protection was necessary on one night only, and the total expense for the season was $91.97 per

FIG. 22.—Lard-pail heaters in cranberry bog

acre. All equipment cost figures are based on prices quoted locally by retail merchants.

ECONOMIC PHASES OF FROST PROTECTION

The costs of orchard-heating equipment, fuel, etc., vary in different parts of the United States, as do the temperatures experienced and the weather conditions which accompany damaging frosts. The quality and quantity of the fruit produced and the prices received for the crops also vary, not only in different districts, but in different orchards in the same district. It is impossible to make a general statement as to the advisability of installing orchard heaters.

Heating must be regarded as a form of crop insurance. The yearly premium on the policy is the total average annual cost of the heating, including interest on investment and depreciation charges. Insuring the fruit crop by installing orchard-heating equipment can

not be directly compared with insuring a house against damage by fire, for it is reasonably sure that the fruit crop will be damaged by frost every few years, while insurance on a building may be carried for a generation without fire damage. As a general rule, during years when orchard-heating expenses are heaviest, there is a shortage of first-grade fruit, which brings better than average prices.

The question of whether orchard heating will pay at a given location depends largely upon the amount and quality of the fruit produced. The cost of protection is the same for a given orchard, whether the trees are young or old, and whether a heavy crop of good-quality fruit or a small, inferior crop is produced. Quantity and quality production must always be considered with the question of installing orchard-heating equipment. Average prices received for the crops are also a factor. In most Pacific coast fruit districts the protection of pears, apricots, cherries, prunes, and almonds in the colder orchards is justified by the returns for the crops. The best-paying varieties of apples also will justify protection costs, while the less popular varieties usually will not.

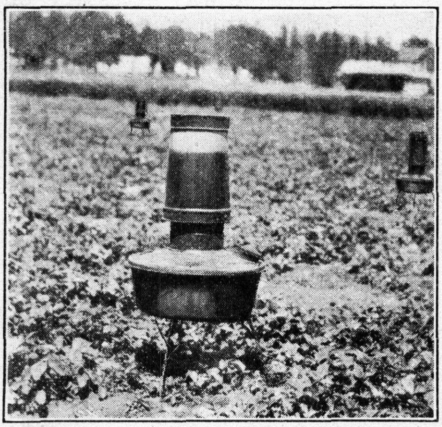


FIG. 23.—Double-stock oil heater on tripod in strawberry patch

If the net profit on a crop were the only consideration in determining whether frost protection will pay, the answer would be negative for most fruit districts in the country. However, when a fruit crop is destroyed by frost the owner's loss is not confined to the net profit he would have made on the crop; the expense of caring for the orchard for a year, interest on the money invested in the orchard, and other similar expenses must be added.

The amount of the loss, therefore, will be the gross value of the crop, less the expenses of picking, packing, etc. The loss calculated on this basis is often very large. Many fruit growers have saved enough fruit in a single season, or even a single frosty night, to pay the total cost of equipping the orchard with heaters and auxiliary equipment, together with the expenses of protecting the orchard during the season.

In considering frost protection for citrus groves, frost damage to the trees is a very important factor. Orange and lemon trees are sometimes defoliated by a heavy freeze and often require five years, or longer, to get back to normal production again. In some districts hundreds of acres of citrus trees have been killed outright by low temperatures. (Figs. 26 and 27.)

There are two conditions under which orchard-heating will not be profitable. The orchard may be located where frost damage is too slight in the long run to pay the expenses of heating, or it may be

in an exceptionally cold section, where damaging frosts occur so often that the cost of protection is too great to be borne by the crops.

The number of cases of the first-mentioned type is smaller than would appear at first thought. The saving of one season's crop,

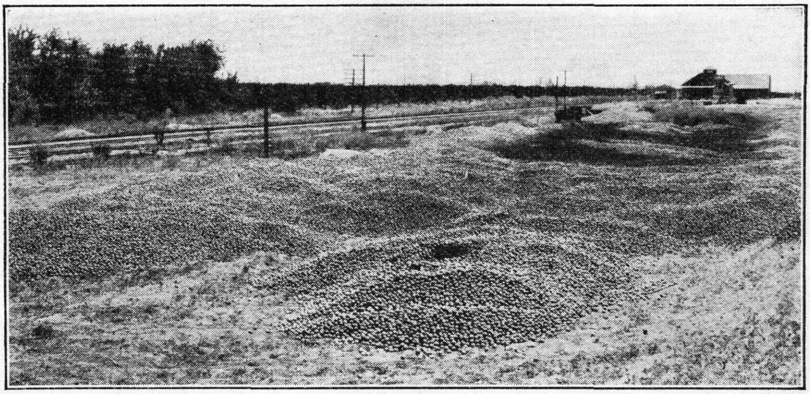


FIG. 24.—A corner of a frozen-orange dump following a severe freeze. This photograph shows fruit culled at only one packing house

which would otherwise have been a total loss, will justify the expense of heating for several years. Many practical growers consider it good business policy to have frost-fighting equipment when it is necessary to use it only one season out of five.

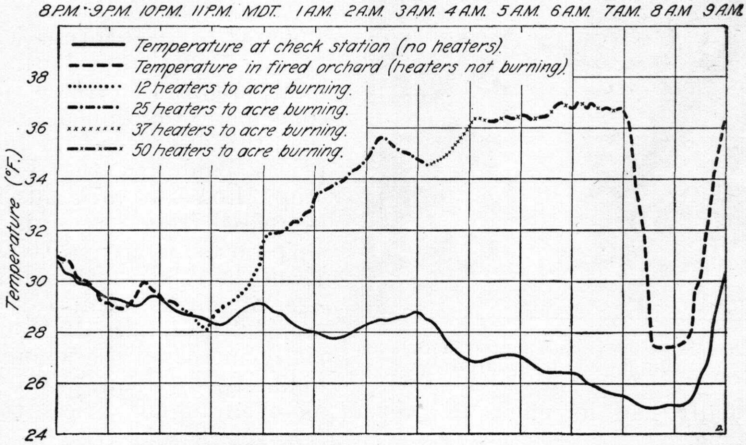


FIG. 25.—Continuous records of the temperature in an orange grove equipped with 50 double-stack oil heaters to the acre, and at a check station outside, during test firing on a frosty night. No heaters were burned near the temperature station in the heated grove. The solid line indicates what the temperature in the fired orchard would have been without heating. The temperature was raised 11° F. with 50 heaters to the acre burning

In cases of the second type it is obvious that the frost hazard is so great that fruit growing will not be profitable in the long run, and the trees will eventually have to be removed.

The statement is often made that the policy of growing fruit on the colder low ground is wrong and that orchards should be confined

to the higher and more frost-free locations. This is often open to question. Certain fruits, such as the apple and the navel orange, are of better quality when grown in localities where the temperature falls almost to the danger point at times. In many irrigated sections the lower cost of irrigating the valley floor as compared with steep hillsides more than makes up for the expense of protecting orchards on the lower ground from frost. Also, the cost of cultivating steep hillsides is greater and valley soils often are more fertile than hillside soils.

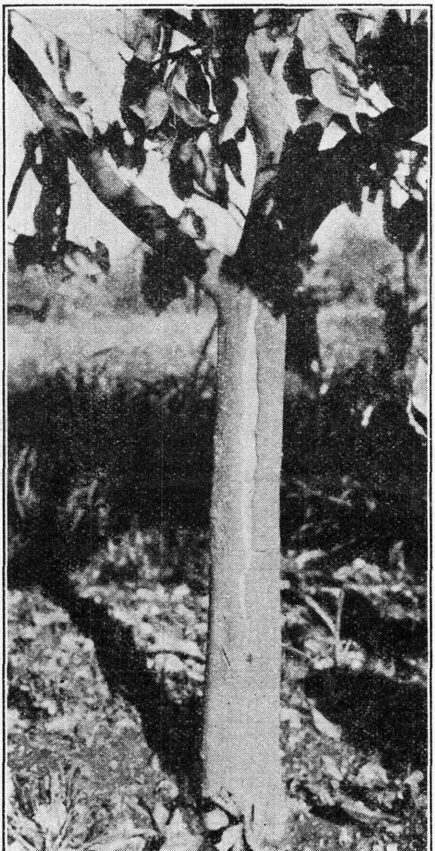


FIG. 26.—Nine-year-old lemon tree with bark split by low temperature

In the event of a general severe freeze which reduces the total supply of fruit in the country, the crops saved by orchard heating tend to maintain more reasonable prices to the consumer. In this way frost protection benefits the entire country. For example, less than 50 per cent of the normal citrus crop was harvested in California in 1922 because of a severe freeze; yet the delivered value of this crop was 75 per cent of normal. Consumers, because of the freeze, paid $30,000,000 more for the same amount of California citrus fruit in 1922 than in 1921. The total cost of the freeze to the consumer was much greater than this, because of the higher prices paid for the Florida crop. Losses to railroads from decreased freight receipts were approximately $20,000,000. Even the relatively small acreage of citrus equipped with orchard heaters in 1922, materially increased the amount of undamaged fruit, and undoubtedly had its effect in preventing even higher prices to the consumer.

An unusually short crop of any variety of fruit may adversely affect its orderly marketing. The ideal condition from a marketing standpoint would be the steady production of good-quality fruit, in amounts which would bring a fair return to the grower year after year. A short crop is likely to cause such high retail prices that the public turns to other fruits, and the cumulative effect of advertising, such as has been done in popularizing citrus fruits, may be lost, temporarily at least.

Although State and Federal laws impose rigid restrictions on the shipment of badly frozen citrus fruits, large quantities of slightly frozen fruit reach the markets after an unusually cold season. This also tends to decrease the consumption in general and is likely to result in a smaller demand and lower prices for excellent-quality fruit during the following season.

A severe freeze sometimes has a very adverse effect on cooperative-marketing organizations. From 85 to 90 per cent of the citrus crop in California is handled through cooperative agencies. These agencies, from the packing houses to the eastern sales organizations, are financed through an assessment on each box of fruit marketed. After a strong organization has been built up through years of effort, it obviously is not possible to reduce the operating expenses to the same extent the crop is reduced when there is heavy frost damage;

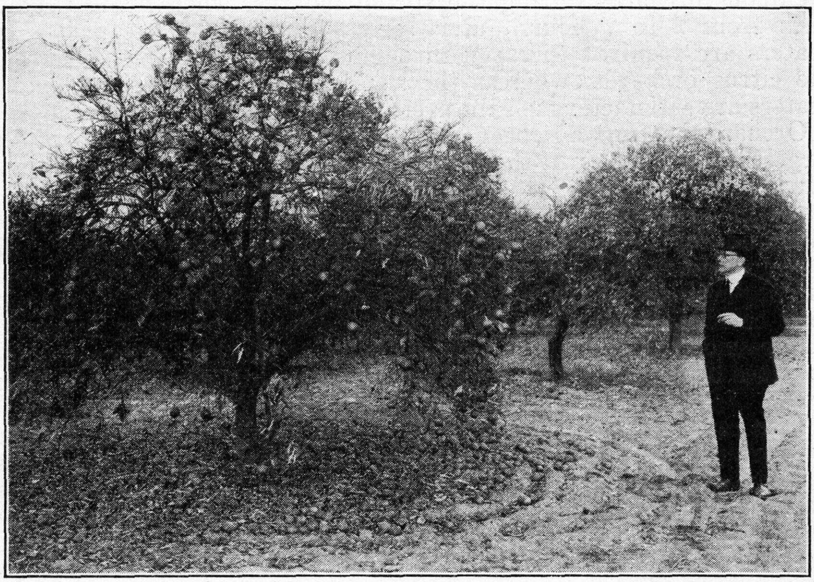


FIG. 27.—Mature navel orange trees defoliated by a freeze

even a slight retrenchment is likely to weaken the organization. Therefore the cost of carrying the cooperative through a freeze year is borne largely by the growers who have saved their crops, and the per box assessment for cooperative-marketing organizations is greatly increased.

EXTENT OF HEATING

The acreage equipped with orchard heaters in the Pacific Coast States has greatly increased during recent years. The increase has been especially large in the citrus districts of California. A survey of the more important sections in the southern portion of the State during the spring of 1928 showed that 51,883 acres of oranges, lemons, and grape fruit, or 24 per cent of the total citrus acreage in the areas surveyed, were equipped with heaters. The acreage with oil heaters

was 22.5 per cent of the total, and that equipped with solid-fuel heaters 1.7 per cent. The combined capacity of all oil-storage tanks listed is 35,843,579 gallons, and 1,767 carloads of oil are required for one filling of the heaters.

COST OF ORCHARD HEATING

Since there is a great variation in the cost of orchard heating in different parts of the country, and even in different orchards in the same district, because of differing costs of equipment, fuel, labor, etc., and to difference in the frost hazard, it is possible to give only a few examples of actual cost accounts furnished by individual fruit growers or corporations. The cost of protecting citrus orchards during the winter months, when firing periods of from 8 to 10 hours are not unusual, is naturally greater than the cost of protecting deciduous orchards during the spring months, when firing usually lasts from 2 to 7 hours. Relatively expensive large-capacity oil heaters are required to carry through the long burning periods in the citrus orchards, whereas the small, cheap lard-pail or briquet heaters are satisfactory for the protection of deciduous-fruit orchards.

Orchard heating has been practiced for 16 years on one of the largest lemon groves in the country, located in southern California. During the winter of 1912–13, a season when the citrus crop in many parts of southern California was practically a total loss and thousands of trees were killed outright in unheated orchards, the crop from this 281-acre grove brought $734,318.07 f. o. b. California. On higher ground on the same ranch, where protection had not been considered necessary, 5-year-old lemon trees were frozen to the ground; the manager states as his belief that the business would not have been profitable since 1912 without means of protection from frost.

This ranch is located on both high and low ground, but only the low ground is protected. Lemons are damaged at higher temperatures than oranges, and as the small green fruit, which is especially tender, is protected here, the heaters are lighted oftener and kept burning longer than in most other orchards. The costs of frost protection on this ranch are for firing about the maximum number of times that would be necessary anywhere in the country.

Records on the cost of protecting 281 acres on this ranch during a 14-year period are shown in Table 1. It will be seen that the return from the fruit saved in 1913 alone, despite the high rate of heating expense, would pay the costs of protection for many years.

TABLE 1.—*Average cost per acre for protecting 281 acres of lemons with oil heaters* [1]

Year	Labor filling, lighting, maintenance	Oil burned in heaters	Depreciation	Interest	Upkeep	Total per acre	Times fired
	Dolls.	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*No.*
1913	45.70	38.35	19.30	17.85	11.55	132.75	19
1914	10.55	12.70	19.10	17.45	7.95	67.75	2
1915	10.65	4.20	17.40	15.50	7.65	55.40	7
1916	21.45	23.20	15.60	13.40	1.10	74.75	20
1917	20.60	26.15	14.30	13.45	5.65	80.15	27
1918	22.15	17.75	13.00	11.25	3.70	67.85	21
1919	17.14	5.53	13.09	8.62	3.44	47.82	14
1920	20.54	5.83	13.44	10.89	1.51	52.[illegible]	12
1921	26.66	6.46	13.44	10.62	5.49	62.67	15
1922	27.24	6.34	20.67	11.36	2.77	68.38	11
1923	47.40	21.99	21.44	10.70	3.00	104.53	30
1924	39.92	22.26	21.46	9.55	1.31	94.50	27
1925	29.14	12.48	21.46	8.80	1.49	73.37	17
1926 [2]	18.27	8.70	4.83	6.28	1.14	39.22	13
Average	25.53	15.14	16.32	11.84	4.12	72.95	17

[1] Small open heaters used in 1913; improved stack oil heaters in later seasons.
[2] In 1926 a new method of accounting was adopted. Cost figures for that year are based on a total of 682 acres of lemons heated.

Average costs for frost protection with lard-pail oil heaters in the Rogue River Valley, Oreg., over a period of five years are given in the tabulation below. These costs are compiled from records kept on a 40-acre pear orchard, in average location and subject to the average frost hazards for pears in this valley.

AVERAGE COSTS FOR PROTECTING 40 ACRES OF PEARS WITH LARD-PAIL OIL HEATERS

Initial cost of equipment

1,100 lard-pail oil heaters, 10-quart size, at $0.40 each	$440.00
1,700 lard-pail oil heaters, 5-quart size, at $0.25 each	425.00
200 improved stack oil heaters, 9-gallon size, at $3 each	600.00
Galvanized-iron tank for ranch storage, 16,800 gallons capacity, installed in orchard	335.00
2 tank wagons, 500-gallons capacity, with buckets and accessories, at $150 each	300.00
8 lighting torches, 1-gallon size, at $2.50 each	20.00
12 minimum recording thermometers, at $3 each	36.00
1 frost alarm with relay and thermometer	30.00
5 flash lights for reading thermometers at night, at $1.50 each	7.50
16,500 gallons of oil in storage tank, at $0.06½	1,072.50
10 gallons lighting fluid in container	3.00
Total investment for 40 acres	3,269.00

Average annual operating expense

Interest:		
3 per cent on $2,193.50 investment in equipment [1]	$65.80	
6 per cent on $1,075.50 investment in fuel	64.53	
		$130.33

[1] Since there is an average annual depreciation rate of 10 per cent on all items of equipment, a fixed interest charge of 3 per cent a year on the total investment will provide for a yearly charge of 6 per cent on the depreciated value.

Depreciation:		
Heaters, 10 per cent on $1,485	$148.50	
Storage, 5 per cent on $335	16.75	
Tank wagons, 10 per cent on $300	30.00	
Thermometers, 5 per cent on $73.50	3.68	
Fuel, leakage, and evaporation, 1 per cent on total store of 16,500 gallons, or 165 gallons, at $0.06½ a gallon	10.72	
		$209.65
Labor:[2]		
Setting pots in orchard	21.60	
Filling pots	27.00	
Refilling pots fired (five nights)	43.20	
Lighting pots (five times a year)	50.00	
Taking up oil	21.60	
Taking up pots	10.80	
Cleaning, storing pots	21.60	
		195.80
Fuel burned:		
6,000 gallons oil, at $0.06½	390.00	
Lighting fuel	18.40	
		408.40
Total annual cost for 40 acres		944.18
Average annual cost per acre		23.60

Average annual costs for frost protection with coal-briquet heaters in the Yakima Valley, Wash., over a period of three years are given in Table 2, and the cost of equipment in the tabulation following. These costs have been figured from records kept on a 303-acre apple and pear orchard. This orchard is planted both on the valley floor and the hillside slopes, and although most of the operating expense has been applied to the lower and colder portion of the orchard, a good idea of the average cost of heating apples and pears with coal-briquet heaters is afforded by considering the entire protected acreage. There is also included succeeding statements showing the average cost for equipment and protection of 50 acres of oranges with double-stack oil heaters.

TABLE 2.—*Average annual operating costs for protecting 303 acres of apples and pears in central Washington, using coal-briquet heaters, 1925, 1926, and 1927*

	1925	1926	1927	Average
	Dollars	*Dollars*	*Dollars*	*Dollars*
Interest, 3 per cent on $15,828.30 equipment [a]	474.85	474.85	474.85	474.85
Interest, 6 per cent on $5,020 fuel	301.20	301.20	301.20	301.20
Depreciation, 10 per cent on $15,828.30	1,582.83	1,582.83	1,582.83	1,582.83
Operation:				
Labor	3,760.73	5,225.00	4,122.70	4,369.48
Upkeep	107.26	223.13	214.55	181.65
Miscellaneous	0	40.88	11.78	17.55
Fuel:				
Coal briquets	1,937.88	6,494.57	4,784.26	4,405.57
Kindling wood	155.45	158.25	278.30	197.33
Lighting fluid	129.82	444.95	93.51	222.76
Total	8,450.02	14,945.66	11,863.98	11,753.22
Average annual cost per acre	27.89	49.33	39.16	38.79

[a] Since there is an average annual depreciation rate of 10 per cent on all items of equipment, a fixed interest charge of 3 per cent per annum on the total investment will provide for a yearly charge of 6 per cent on the depreciated value.

[2] Labor is charged for at the rate of 50 cents an hour for night work in firing heaters; 40 cents an hour for other jobs.

INITIAL COST OF EQUIPMENT

Heaters:		
18,000 coal-briquet heaters	$12,327.71	
18,000 field-storage boxes for fuel	2,312.18	
Lighting torches	396.80	
		$15,036.69
Storage:		
Main storage bunkers for fuel	356.05	
20 steel drums, 50-gallon size, at $3 each, as containers for lighting fluid	60.00	
		416.05
Distributing system:		
Briquet forks for handling fuel	48.24	
Funnels for filling heaters, etc	66.32	
		114.56
Thermometers:		
72 short-range minimum thermometers at $3	216.00	
30 flash lights at $1.50	45.00	
		261.00
Fuel:		
400 tons coal briquets at $12 a ton	4,800.00	
1,000 gallons lighting fluid, gasoline and kerosene, at $0.22 a gallon	220.00	
		5,020.00
Total investment for 303 acres		20,848.30

AVERAGE COSTS FOR EQUIPPING AND PROTECTING 50 ACRES OF ORANGES IN SOUTHERN CALIFORNIA WITH DOUBLE-STACK OIL HEATERS

Initial cost of equipment

Heaters:		
2,800 double-stack oil heaters, 9-gallon size, at $2.32 each, delivered	$6,496.00	
12 lighting torches, 1-gallon size, at $2.50	30.00	
		$6,526.00
Storage:		
105,000-gallon galvanized-iron tank	1,179.00	
Concrete foundation for tank	50.51	
Container for lighting fluid, 50-gallon size	3.00	
		1,232.51
Distributing system:		
2 tank wagons, 450-gallon size, at $150	300.00	
Pipe line from storage tank to orchard	209.13	
Tank-wagon accessories: Pipes, connections, valves, hose, buckets, etc	50.00	
Portable pump for emptying heaters	20.00	
		579.13
Thermometers:		
12 minimum-recording thermometers at $3	36.00	
1 frost alarm	30.00	
5 flash lights at $1.50 for thermometer reading	7.50	
		73.50
Fuel:		
100,000 gallons heater oil in tank, at $0.04	4,000.00	
40 gallons lighting fluid (kerosene and gasoline) at $0.20	8.00	
		4,008.00
Total investment		12,419.14

Average annual operating expense

Interest:		
3 per cent on $8,411.14, investment in equipment [3]	$252.33	
6 per cent on $4,008, investment in fuel	240.48	
		492.81

[3] Since there is an average annual depreciation rate of 10 per cent on all items of equipment, a fixed interest charge of 3 per cent per annum on the total investment will provide for a yearly charge of 6 per cent on the depreciated value.

Depreciation:			
Heaters, 10 per cent on $6,526		$652.60	
Storage, 5 per cent on $1,232.51		61.63	
Distributing system:			
Tank wagons, 10 per cent on $300	$30.00		
Pipe line, 3 per cent on $209.13	6.27		
Accessories, 20 per cent on $70	14.00		
		50.27	
Thermometers:			
5 per cent on $73.50		3.68	
Fuel:			
Leakage and evaporation, 1½ per cent of total store, or 1,500 gallons at $0.04		60.00	
			$828.18
Operation:			
Setting pots in orchard		38.00	
Filing pots		70.35	
Refilling pots after firing (10 times)		116.02	
Lighting pots (10 times a year)		160.00	
Taking up oil at end of season		90.57	
Taking up heaters		32.43	
Painting heaters every four years at $0.16 each a year		112.00	
			619.37
Fuel:			
17,129 gallons oil burned in heaters at $0.04		685.16	
Lighting fluid, 28 gallons at $0.20		5.60	
			690.76
Average annual cost for 50 acres			2,631.12
Average annual cost per acre			52.62

DAMAGING TEMPERATURES

So many factors must be taken into consideration in determining whether a given temperature will cause damage to fruits, buds, or blossoms, that the matter is one of considerable complexity. The length of time the low temperature persists, the vigor of the tree, and the weather preceding the frost, all have considerable influence on the amount of damage that will be done.

Other conditions being the same, the fruit or blossoms on a weak, undernourished tree will show more injury than those on a vigorous tree after both have been subjected to the same low temperature.

DECIDUOUS FRUITS

When soil and atmospheric conditions are favorable for growth, as during warm, sunshiny weather, the sap is likely to be watery and its freezing point relatively high. For this reason a frost which follows a period of weather favorable for rapid growth will cause more damage than the same temperature following a period of cold, cloudy weather and consequent slow growth. Under certain conditions the blossoms and fruit may endure low temperatures without damage, which under other conditions would destroy the greater portion of the crop. In the following paragraphs data are given regarding temperatures which have caused damage to various deciduous fruits in different stages of development. These data are based on field observations made by Weather Bureau officials over a long period of years, and are considered safe as a basis of recom-

mendations for successful orchard-heating operations. Some fuel will be wasted in maintaining temperatures according to these recommendations, but the grower who has orchard-heating equipment can not afford to take chances. All temperatures mentioned are sheltered-thermometer readings.

Temperatures that will be endured for 30 minutes or less by deciduous fruits in various stages of development are given in Table 3. It must be admitted that these data are unsatisfactory because they do not go into enough detail. The three stages of development given are not sufficient to cover all the changes in susceptibility to damage which are found during the period of development of a fruit bud through the blossom stages to the green fruit. Detailed information to supply the deficiency is not available except in the case of a few fruits.

TABLE 3.—*Temperatures endured for 30 minutes or less by deciduous fruits (sheltered thermometers)*

Fruit	Stage of development			Fruit	Stage of development		
	Buds closed but showing color	Full bloom	Small green fruits		Buds closed but showing color	Full bloom	Small green fruits
	°F.	°F.	°F.		°F.	°F.	°F.
Apples	25	28	29	Apricots	25	28	31
Peaches	25	27	30	Prunes, Italian	23	27	30
Cherries	28	28	30	Almonds	26	27	30
Pears	25	28	30	Grapes	30	31	31
Plums	25	28	30	Walnuts, English	30	30	30

More detailed information regarding temperatures which will damage pears and apples at different stages of advancement has been secured through the systematic checking of damage caused by known low temperatures over a long period of years. Temperatures which will be endured for 30 minutes or less by different varieties of these fruits are shown in Tables 4 and 5. More damage will result from a given temperature when the humidity is low than when it is relatively high.

TABLE 4.—*Temperatures endured for 30 minutes or less by different varieties of apples (sheltered thermometers)*

Variety	Stage						
	1	2	3	4	5	6	7
	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Delicious	25	25	26	27	28	28	29
Winesap	25	25	26	26	28	28	29
Jonathan	23	25	25	26	28	28	29
Rome Beauty	23	23	24	25	27	28	29
Yellow Newtown	23	23	24	25	27	28	29

Stages: 1. Buds widely separated in cluster, but still tightly closed and showing no color. 2. Center buds showing color; other buds breaking open. 3. All buds showing color. 4. Center bud in full bloom; other buds opening. 5. Full bloom. 6. Petals falling. 7. Small green fruits.

TABLE 5.—*Temperatures endured for 30 minutes or less by different varieties of pears (sheltered thermometers)*

Variety	Stage				
	1	2	3	4	5
	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Beurre Bosc	25	27	29	29	29
Anjou	25	27	30	30	29
Howell	25	27	29	29	29
Comice	24	26	28	28	29
Bartlett	24	27	28	28	29
Winter-Nelis	24	26	27	28	29

Stages: 1. Separated in cluster, but showing no color. 2. Buds showing pink. 3. Buds showing white. 4. Full bloom. 5. Small green fruits.

Different varieties of the same fruit often differ considerably in their susceptibility to frost damage. The Beurre Bosc pear is more susceptible to damage by frost than most other commercial varieties of pears at similar stages of development, whereas the Winter Nelis is hardier than most other. Pear blossoms of the Anjou variety may be injured by frost without the blackening of the ovules, the injury being evidenced later through an unusually heavy dropping of the small green fruits.

With the buds still tightly closed and showing no color, although widely separated in the cluster, Delicious and Winesap apple buds will suffer about 15 per cent more damage than Jonathan, Rome Beauty, or Yellow Newtown, with a minimum temperature of 27° F. and a low humidity (dew point 19° F.). In a later stage of development, with the center buds in full bloom and the other buds about to open, a minimum temperature of 25° F. with a duration below 32° F. of about seven hours and a dew point of 32° F. or higher, damage to apples is approximately as follows: Delicious, 88 per cent; Stayman and Winesap, 22 per cent; Grimes Golden, 10 per cent; Jonathan, Rome Beauty, and Yellow Newtown, 2 per cent. Throughout all stages of development of buds, blossoms, and small green fruits, the Delicious appears to tbe the most susceptible and the Yellow Newtown the least susceptible to frost damage.

The fruit buds of nearly all deciduous fruits are extremely susceptible to damage during the period of from 24 to 48 hours before they open into full bloom. The petals are still folded, but the flowers are growing rapidly and are extremely tender. Buds in this condition often are injured by temperatures as high as those given in Table 3 for small green fruits. Fortunately, most deciduous-fruit trees come into bloom gradually, so that, even if all the buds about to open at one time are killed, the size of the crop is not reduced materially. From 50 to 90 per cent of the blossoms on most varieties of fruit trees can be killed without affecting the size of the crop harvested, provided the uninjured buds are scattered throughout the trees. (Fig. 28.) Buds of the Beurre Bosc pear often open almost simultaneously, and a low temperature just before the blossoms open sometimes destroys most of the crop.

At the time generally designated as "full bloom," most deciduous-fruit trees have large numbers of fruit buds which are still tightly

closed, in addition to the flowers which are fully open, making the loss of the entire crop, or even the greater portion of the crop, on one moderately cold night extremely improbable at this stage. In southern Oregon a temperature below 32° F. for more than 13 consecutive hours, with a minimum temperature of 21.5° F., while the trees were in full bloom, reduced the final crops of Bartlett, Anjou, Comice, and Winter Nelis pears only about 20 to 25 per cent, although the reduction in grade due to frost marking was responsible for a loss that would have more than paid for the expense of orchard heating. This factor has led fruit growers in some districts to believe that frost can do no damage before the fruit has set. Some growers even follow the hazardous practice of leaving the heaters unlighted on frosty nights during the blooming period. While a single frosty night at the time of full bloom seldom materially affects the size of the final crop of pears, apples, or prunes, a series of heavy frosts, each killing a portion of the blossoms, may leave too few undamaged blossoms for a full crop.

The most dangerous stage in general comes after the petals have fallen and the fruit has set. All of the fruit is then in nearly the same condition, and the entire crop may be killed in a single night. It is at this time that orchard-heating operations should be most carefully conducted. Apples and pears at this stage of development usually are not seriously injured by a temperature of 28.5° F. for 30 minutes or less, provided the duration of temperature below 32° F. does not exceed two hours. If the temperature drops to 29° F. at sunrise, and has not been below 32° F. more than two hours, heating is unnecessary. However, if it appears that the lowest temperature during the night will be below 29° F., or if the temperature falls below 32° F. more than two hours before sunrise, heaters should be lighted and the temperature maintained as near 31° F. as possible throughout the remainder of the night.

Small, green apricots are extremely tender just after the shucks (dried calices) have dropped and before the pits have hardened. Apricots in this stage of development have been injured at long-continued temperatures of 31° F., and many growers believe it necessary not to allow the temperature to fall below 32° F. as long as the pits are soft.

From what little data are available, Italian prunes appear to be exceptionally hardy before the fruit has set. In eastern Washington when prunes were generally showing color but none were in full bloom, they sustained practically no damage following a frosty night with temperature below 30° F. for seven consecutive hours, with the lowest temperature 22° F. Only scattered blossoms were damaged. Later in the same year, when the trees were estimated to be 85 per cent in full bloom, temperatures below 30° F. for more than 10 consecutive hours, with the lowest temperature 15.7° F., killed only about 70 per cent of the blossoms. Practically all the blossoms not open at the time of the frost escaped injury. The prune crop harvested in the fall was about 75 per cent of normal, 10 acres of orchard yielding 3½ tons of fruit.

With the crop in the small green-fruit stage, a temperature below 30° F. slightly more than five hours, with the lowest temperature

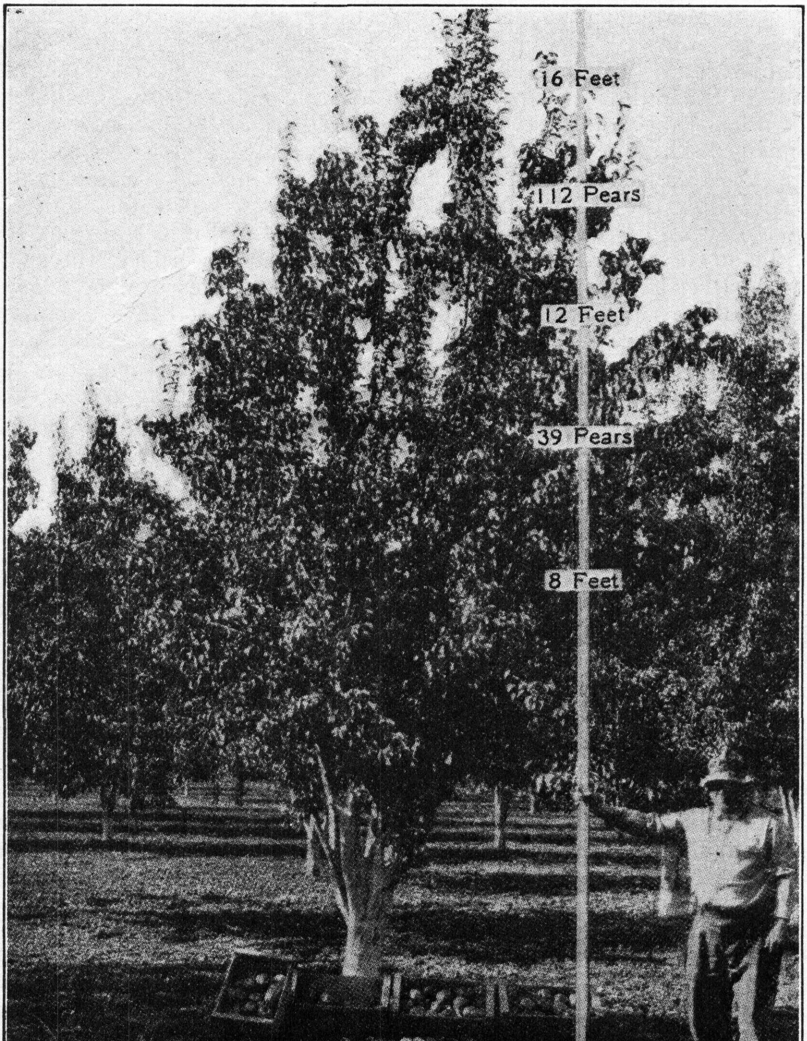


FIG. 28.—The effect on the crop of a Comice pear tree of the stratification of the air on cold nights. The orchard was not protected and all the fruit in the lower portion of the tree was destroyed by frost. The tree bore no fruit below 8 feet; only 39 pears between 8 and 12 feet, and 112 pears above 12 feet. This was typical of the entire orchard

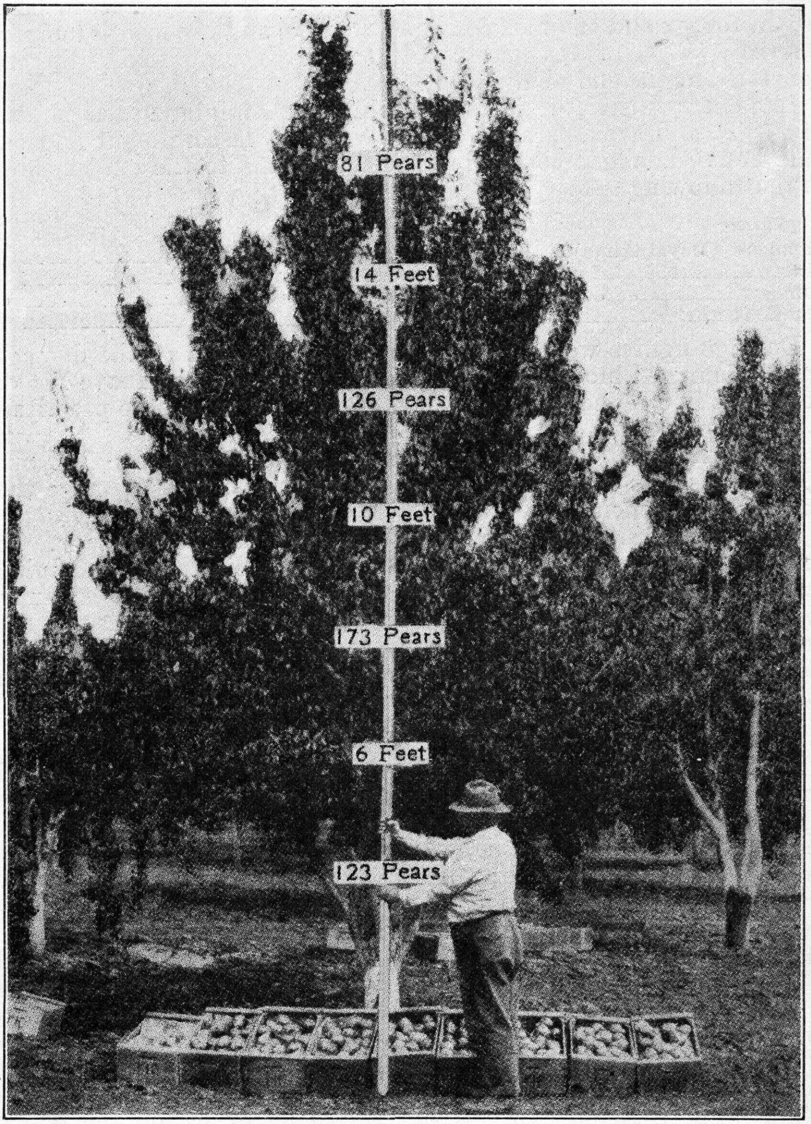


FIG. 29.—The effect on the crop of the Comice pear tree shown in Figure 28 of the use of orchard heaters the year following. The yield was 123 pears below 6 feet, 173 between 6 and 10 feet, 126 between 10 and 14 feet, and 81 pears above 14 feet

26° F., caused a loss of approximately 75 per cent of the fruit on the trees.

Few data are available regarding temperatures which will damage cherries. Bing cherries about one-third in full bloom suffered about 33 per cent damage on a frosty night with the temperature below 30° F. for six and one-half consecutive hours and the lowest temperature 24.3° F. This loss in bloom did not reduce the size of the crop harvested at the end of the season.

In a cherry district in eastern Washington a minimum temperature of 27° F. and a temperature of below 32° F. lasting eight and one-half hours damaged cherry buds and blossoms to the extent shown in the following list:

Variety	Stage	Damage (per cent)
Napoleon (Royal Anne)	Buds closed but showing color	56
Bing	Buds closed but showing color	30
Lambert	A few blossoms open	22
Black Tartarian	Full bloom	23

Damage figures were obtained by an actual count of the damaged and undamaged blossoms. The damage shown in the above list did not result in a reduction of the final crops. All trees bore practically a full crop of fruit at the end of the season.

From the small amount of data available it appears that open cherry blossoms are somewhat more resistant to frost damage than buds about to open.

English walnuts are extremely susceptible to frost damage. Experiments conducted in southern California indicate quite definitely that a temperature of 29° F. for 30 minutes will cause serious damage to blossoms, small green nuts, and tender young foliage. The temperature in walnut groves should not be allowed to fall below 30° F. at any time after the trees begin to put out blossoms and foliage in the spring.

FROST MARKING

Pears and apples often are severely injured by frost, but remain on the trees until maturity, making second-grade or cull fruit. Damage of this type is divided into two classes: (1) The growth of a coarse, woody, russet tissue, which covers a portion or even the entire outside of the fruit, and (2) the development of misshapen fruits in which the seeds have been destroyed by frost.

The first type of damage is confined almost entirely to pears, although frost-marked apples are sometimes found. It was formerly believed that the russet frost marks were caused by late frosts, which occurred after the fruit had set and the petals had dropped. Careful observation over a 10-year period has proved that marking almost invariably takes place either when the tree is in full bloom or prior to full bloom. Marking takes place at a higher temperature on a damp night than on a dry night, a coating of ice on the bud or blossom being especially conducive to this type of injury. Considerable marking is likely to take place on a damp night during the bud or blossom stage, if the temperature falls to 26° F. As a general rule the Bartlett will show a larger percentage of russet frost marking at a given temperature than any other variety, and the Anjou the next largest. Russet frost marks are seldom found on other varieties of pears.

The destruction of the ovules or the seeds, causing misshapen fruits, may take place at any stage of the development of the buds, blossoms, or small green fruits. Bartlett pears often show both types of damage, being frost marked, seedless, and misshapen. Misshapen fruits due to seedlessness caused by frost are found most often in the Bartlett, with the Beurre Bosc a close second. (Fig. 30.) Few odd-shaped Anjou and practically no odd-shaped Comice or Winter Nelis fruits are ever found, as the destruction of the seeds usually causes the fruit to drop. Seedless and misshapen apples, resulting from frost damage, are not uncommon, although pears are much more susceptible to this type of injury.

The use of orchard heaters to prevent the lowering of the quality of the fruit by frost marking is often abundantly justified, even though the size of the crop may not be affected.

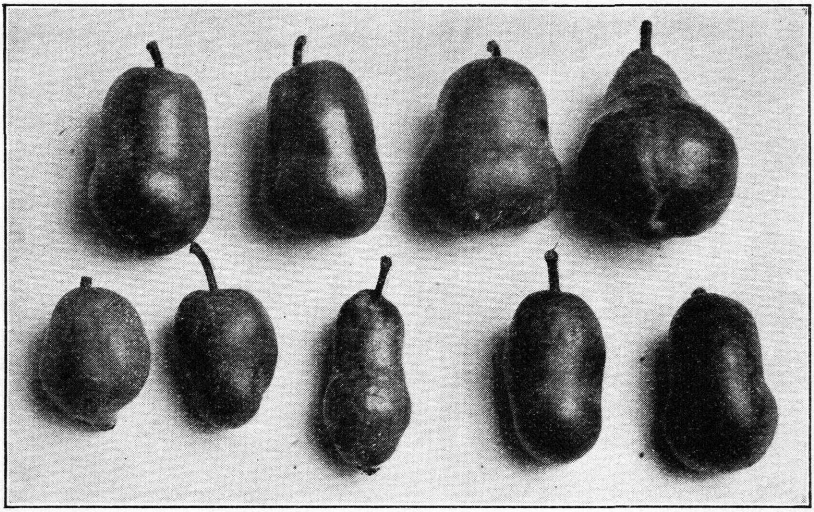


FIG. 30.—Odd shapes assumed by Bartlett pears in which the seeds had been killed by frost. The pear in the upper right hand corner of the photograph is normal in size and shape

CITRUS FRUITS

Attempts to determine definite critical temperatures for citrus fruits are confronted with the same limitations as are attempts to determine them for deciduous fruits. The length of time the low temperature persists, the vigor of the tree, the weather preceding the frost, the maturity of the fruit, and the rate at which the temperature has been falling, are all factors in determining the amount of frost damage to oranges, lemons, and grapefruit that will result from a given temperature. The size of the fruit is also important, since small fruits cool more rapidly than large ones.

The thick, pithy rind of the orange is a poor conductor of heat, and the protection it affords causes the temperature of the interior of the fruit to fall more slowly than the temperature of the outer air. When the air temperature is falling rapidly the interior of the fruit may be as much as 7° warmer than the air surrounding it, and

the temperature inside the fruit may lag from an hour to an hour and a half behind the temperature of the air.

After the fruit begins to freeze, its temperature will remain at, or very near, the freezing point of the orange until it is frozen solid, no matter how low the temperature in the orchard may fall. (Figs. 32 and 33.) The temperature at which freezing of the fruit begins is slightly different in different oranges of the same variety, even on the same tree. In experimental work done by the Weather Bureau, the freezing points of ripe navel oranges varied from 27° to 28° F. Half-ripe Washington navels began to freeze at fruit temperatures of from 28° to 29° F., and green navels at from 28.5° to 29.5° F. The fruit itself must reach the temperature given above before freezing will begin; the air temperature may be, and usually is, several degrees lower.

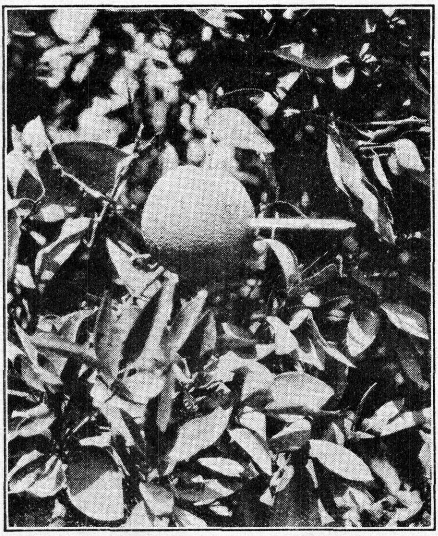


FIG. 31.—Fruit thermometer inserted in an orange to determine when firing is necessary. A small puncture is made in the rind and the thermometer bulb is inserted just under the rind into the pulp. See Figures 32, 33, and 34 for records made with these thermometers

Citrus fruits on the outside of the tree cool more rapidly than those sheltered by foliage; therefore, on a clear, calm, frosty night, the most exposed oranges on a tree may be as much as 3° colder than those on the interior of the tree. (Fig. 32.) It often happens that a moderately low temperature will freeze only the exposed portion of the rind of the orange, giving it a water-soaked appearance, usually called the "water-mark." If the orange is colored, the portion of the rind that has been frozen turns a very light yellow on the day following the frost. Such oranges are called "shiners."

The problem of determining what temperatures will damage citrus fruits is further complicated by a phenomenon known as "undercooling," by which is meant the cooling of the fruit below its freezing point without the formation of ice. Navel oranges have been known to cool as much as 3° below their freezing point before freezing began. (Fig. 32.) Undoubtedly oranges are often undercooled several degrees and afterwards the temperature rises again without the formation of ice and without any damage to the fruit resulting. The first formation of ice crystals in an undercooled fruit is accompanied by a rise of the fruit temperature to approximately its freezing point. The amount of undercooling which the fruit will undergo on a given night can not be determined in advance, although there appears to be less undercooling when the fruit is covered with ice than when it is perfectly dry. However, until further information regarding undercooling of fruit on the tree under natural conditions

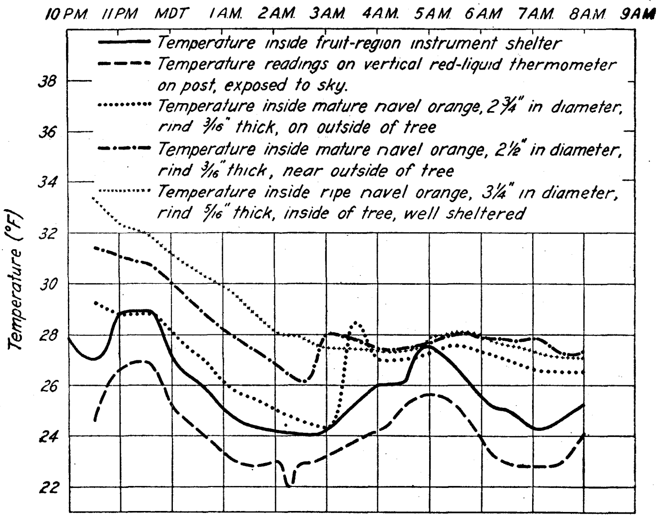


FIG. 32.—Temperatures inside ripe navel oranges, exposed to the sky, partially sheltered, and completely sheltered by foliage, respectively; also temperature shown by thermometer in standard instrument shelter and by thermometer attached to post, exposed to sky. All thermometers and fruits 4½ feet above ground. The temperature of the exposed orange fell to 24.4° F. before freezing began, while the partially sheltered one began to freeze about 20 minutes earlier at a temperature of 26.1° F. None of the fruits began to freeze until after the exposed thermometer had indicated a temperature of 22.3° F. and had shown a reading below 27° F. for about 5 hours

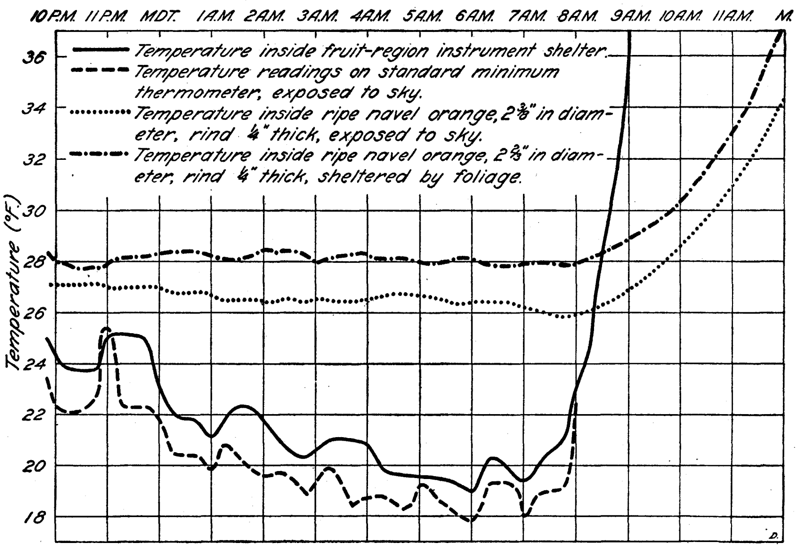


FIG. 33.—Temperatures inside two ripe navel oranges, one exposed to the sky and the other sheltered by foliage; also readings of two standard minimum thermometers, one inside standard instrument shelter and the other exposed to the sky

NOTES.—The fruit in this orchard was a total loss, due to the low temperatures on this one night. Both the sheltered and exposed oranges had already begun to freeze when the observations were begun. These records illustrate in a striking manner the fact that the temperature inside the orange after freezing begins will not fall much below the freezing point of the orange until it is frozen solid, no matter how low the temperature of the air in the orchard may fall. This is a point that must be kept in mind when using fruit temperatures to determine when protection is necessary.

is obtained, it will not be practicable to take this factor into consideration in determining when to light the heaters.

In general, the nights on which heating will be necessary to protect oranges and grapefruit may be divided into two classes. The first class will include those on which a local frost occurs, when the cooling is due principally to loss of heat by radiation. Such nights usually follow warm afternoons. The temperature drops rapidly but does not reach 27° F. until 2 or 3 o'clock in the morning. The fruit temperature is likely to be several degrees above the air temperature on such nights, and so long as the air temperature continues to fall steadily, lighting of heaters to protect ripe, or nearly ripe navel oranges or grapefruit can be delayed until the sheltered thermometer registers 26° F. Under similar conditions, heating for the protection of green navels or Valencias should start at 27° F. In any case it is best to keep the temperature about 28° F. after heating starts.

The second class of nights on which heating is necessary includes the "freeze" nights. The preceding afternoons are usually cold and windy, often with a cloudy sky. The temperature falls below the danger point early in the night and remains there until sunrise; or the temperature may fall only slightly below the freezing point of the fruit early in the night and remain practically stationary until morning. On such nights it is necessary to light the heaters before the temperature has fallen much below the freezing point of the fruit. Lighting of heaters for nearly ripe navels should be started when the sheltered thermometer reaches 27° F. Green navels or Valencias should be heated when the temperature has been stationary at 28° F. for two hours or when the temperature is falling slowly and has reached 27.5° F. On a night when the temperature falls to the previously indicated freezing point of the fruit before 1 a. m., the temperature in groves protected by heaters should be maintained at this point until morning.

It is even more difficult to advise regarding temperatures at which heaters should be lighted for the protection of lemons. Lemon trees carry buds, blossoms, and fruit, in all stages of development, at the time protection is necessary. Open blossoms, buds about to open, and small green fruits one-fourth inch or less in diameter, are most susceptible to damage, sometimes showing slight injury following temperatures of 30° F. for 30 minutes. However, temperatures as low as 29° F. for 30 minutes are often endured at these stages without damage. Tree-ripe fruits are damaged at only slightly lower temperatures than the small green fruits. Green fruits more than one-half inch in diameter, and small, tightly closed buds are relatively hardy. (Fig. 34.) Green fruits three-fourths inch in diameter or larger have been known to withstand temperatures below 29° F. for seven and one-half hours, and below 26° F. for two and one-half hours, with a minimum temperature of 24.2° F., without injury. Growers who attempt to save only the larger green fruits usually will be safe in allowing the sheltered thermometer to fall to 27° F. for 30 minutes or less, maintaining the temperature in the orchard at 28° F. or higher after the heaters are lighted.

Green lemons which are frozen when about one-fourth inch in diameter sometimes remain on the tree and grow to maturity but

make only rough, thick-skinned, juiceless fruits of no commercial value. (Fig. 35.)

DAMAGE TO CITRUS TREES BY FROST

The amount of injury to citrus trees during a freeze will depend to a great extent on the weather preceding the freeze. If the soil and air have been warm and the trees have had plenty of moisture, they will be in a succulent growing condition, and a freeze will cause the maximum amount of damage. If the weather has been cold and cloudy, so that the trees are semidormant, damage by a freeze will be considerably less. Trees that have been weakened by lack of proper care are damaged by higher temperatures than those that have been kept strong and vigorous. Mature navel orange trees in

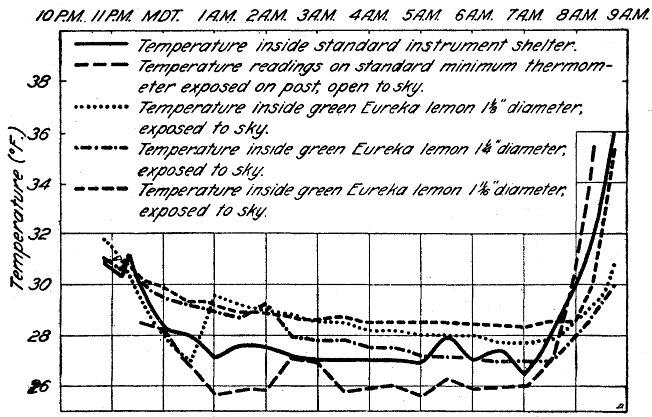


FIG. 34.—Temperature inside small green Eureka lemons of different sizes, all exposed to the sky; also temperature inside standard instrument shelter and that indicated by standard minimum thermometer exposed to sky. Note that the smallest lemon was undercooled about 2.5° F. before it began to freeze, about 12.30 a. m.

southern California, in rather poor condition, were about 75 per cent defoliated by a temperature below 20° F. for six hours, with a minimum temperature of 18° F., during the freeze of 1922. Another navel orange grove near by, in good condition, was about 10 per cent defoliated by a minimum temperature of 19.8° F. on the same night. On the morning of January 3, 1924, a mature California orange grove endured a temperature of 16° F. for 1½ hours, with 13 hours below 27° F., with only about 10 per cent defoliation. In the last case the trees were almost dormant whereas in 1922 they had been in growing condition all winter.

A mature California lemon grove was entirely defoliated during the 1922 freeze by a minimum temperature of 20° F., and the bark on the trunks of 10-year-old trees was split on a night when the minimum temperature fell to 19° F. (Fig. 26.) During the winter of 1924–25 several temperature stations were maintained by the Weather Bureau in a 20-year-old lemon grove. In the lower portion, where the lowest temperature was 22.6° F., the trees were completely defoliated, and on slightly higher ground, where the lowest temperature was 24° F., they were about 50 per cent defoliated, while on

still higher ground, where the lowest temperature was 26.5° F., only the tender new growth was killed. In the San Joaquin and Sacramento Valleys in California the trees become more nearly dormant under average winter conditions than in southern California and consequently will endure without damage somewhat lower temperatures.

All the evidence at hand indicates that frozen oranges tend to hang on the trees during a dry winter but are likely to drop from

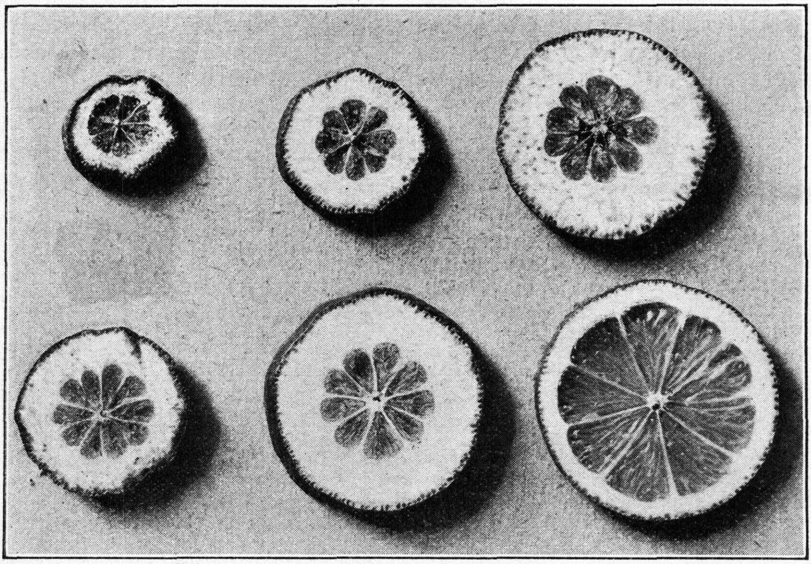


FIG. 35.—Eureka lemons of varying sizes, which were damaged by frost when very small, showing abnormal development of rind. These fruits were picked 11 months after the frost occurred. The lemon in the lower right-hand corner of the photograph is a normal fruit of packing size (2 inches in diameter)

the trees soon after a freeze which occurs during a winter with plentiful rainfall.

NOTES.—At the time these small lemons had reached picking size, about 60 per cent were culled at the packing house and the remainder shipped in low grades. The loss of very small fruits, buds, and blossoms, due to the frost, was heavy, although impossible to estimate accurately. A large percentage of the small fruits which were injured at the time of the frost continued to grow until they reached picking size. However, they were nearly all rind, contained practically no juice, and were of no commercial value. (Fig. 35.)

METEOROLOGICAL INSTRUMENTS AND EXPOSURES

It is well known that a thermometer exposed to the sky on a clear, calm night loses heat by radiation to the sky and shows a temperature lower than the actual temperature of the air surrounding it. In other words, the exposed thermometer merely indicates its own temperature. This may be 1°, 2°, or even 3° lower than the temperature of the air surrounding the thermometer, depending on the amount of moisture in the air and the type of thermometer used. (Figs. 32, 33, and 34.) Generally speaking, dark-colored substances radiate heat more rapidly than lighter-colored, or those with a high polish.

It is often suggested that because the orchard trees are not sheltered from the sky unsheltered thermometers should be used to deter-

mine the temperatures which damage the fruit. However, there is no reason to believe that an exposed thermometer will indicate correctly the temperature of the buds, blossoms, or fruits, especially since a dark-green fruit will radiate heat to a clear sky more rapidly than a white blossom.

The lower portion of a tree is usually more or less screened from the sky by adjoining trees, and blossoms or fruit in the interior of a tree are almost completely screened by the leaves, branches, and fruit above. The most exposed portion, the part cooled most by radiation to the sky, is the top, and this cooling is nearly always more than offset by the difference in air temperature between the top and the base of the tree, due to temperature inversion. (Fig. 28.)

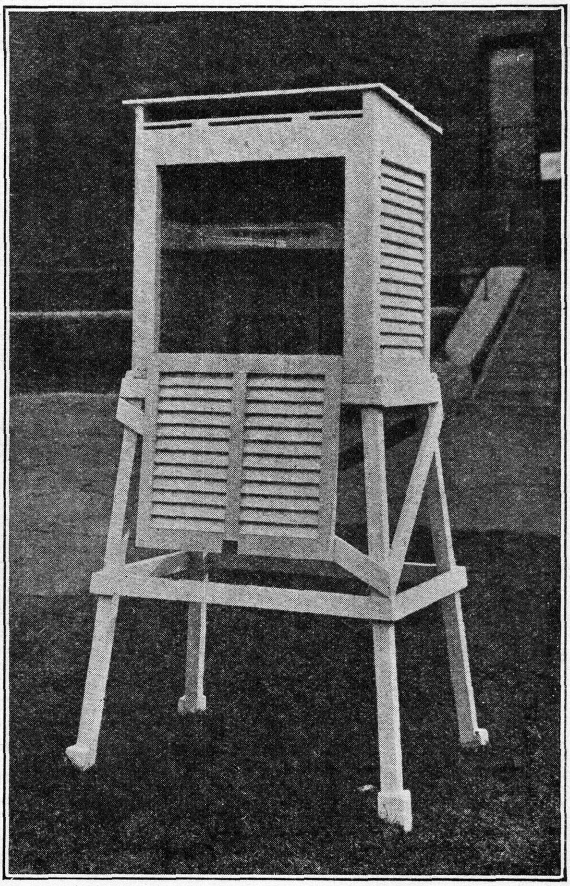


FIG. 36.—Standard cotton-region instrument shelter used by Weather Bureau

The object in sheltering a thermometer is to eliminate, so far as possible, the effects of loss of heat by radiation, and to obtain, as nearly as possible, the actual temperature of the air. As a matter of fact, the air inside an instrument shelter is usually slightly colder than that outside the shelter on a clear, calm night, because the shelter itself is cooled by radiation to the sky. The only temperature observations which are at all comparable one with another are those made with sheltered thermometers.

It has been stated that a relatively large amount of heat is required to change liquid water to water vapor. Evaporation is going on at all times, even when the temperature is below freezing. When a thermometer bulb is covered with a film of water or ice, or contains frost on the bulb, the evaporation that is taking place absorbs heat from the thermometer and cools it to below the temperature of the air. The amount of cooling depends on the amount of moisture in the air and the rate at which *the air* is moving past the thermometer.

A satisfactory shelter must screen the thermometer from the sky and from direct sunlight and must also prevent the deposit of moisture on it from any source. Free circulation of air is also an important requirement for a satisfactory exposure. It is essential, therefore, that a thermometer shelter allow as free a circulation of air as possible without sacrificing the elements of protection from sunlight and liquid or frozen moisture. Standard Weather Bureau shelters have double roofs to prevent undue warming of the inside air by the sun's rays, and the bottoms and sides are as open as possible. (Figs. 36 and 37.)

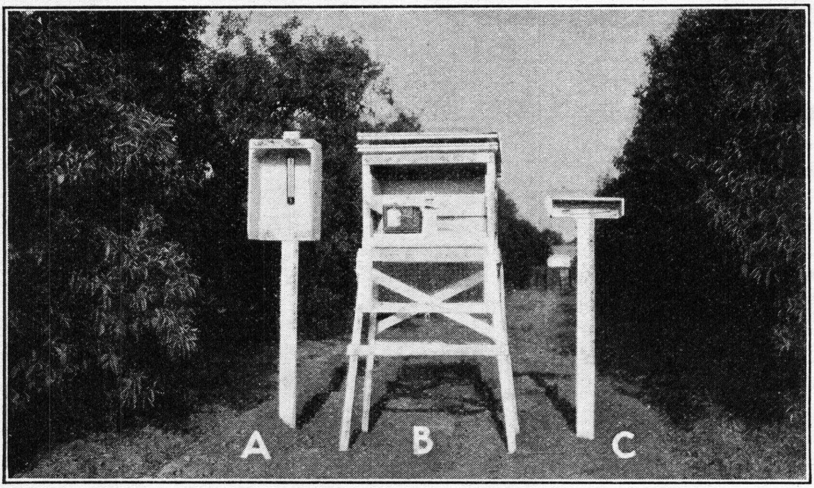


FIG. 37.—A, Rough type of shelter for vertical thermometer, which may be constructed from an apple box attached to a post and firmly anchored to prevent vibration, the bottom and front of the box being open; B, Weather Bureau fruit-region instrument shelter, showing exposure of thermometers and thermograph, suitable for use only in fall, winter, and spring, recommended for sheltering thermometers and thermographs used in orchard-heating work; C, rough type of shelter for horizontal minimum thermometer, made with two thin boards about 9 or 10 inches wide and 16 or 18 inches long, placed at right angles to each other, one constituting the back of the shelter and the other furnishing a cover for the thermometer. The shelter is secured to a post about 5 feet high, and the top board is hinged so that it can be thrown back when setting thermometer

In exposing all thermometers used for determining orchard temperatures the foregoing principles should be borne in mind. Whenever possible, standard instrument shelters should be used. If this is not practicable, a fairly satisfactory thermometer shelter can be constructed from an apple box attached to a post, firmly anchored to prevent vibration, the bottom and front of the box being open. (Fig. 37.) All shelters should be faced squarely toward the north, in order to prevent direct sunlight from striking the thermometers during the day, and should be painted white, to reduce cooling by radiation at night. Thermometers should be 4½ feet above the ground.

In reading a thermometer on a cold night, care should be taken not to breathe directly on it, and an electric flash light should always be used in making readings. When matches, candles, or lighting torches are used to illuminate the thermometer scale, the temperature may be raised a degree or more before the reading can be made; this may result in loss of fruit occasioned by failure to light the heaters in time.

Every orchardist who has frost-fighting equipment should have at least two accurate, dependable thermometers, preferably of the type which register the minimum temperature. In larger orchards there should be one thermometer to each 5 acres. Thermometers should be checked for accuracy at least once each year, and those found to be in error more than 1° near the freezing point should be discarded. Inaccurate instruments should be marked so that the correction can be applied when making a reading. Information regarding types of thermometers developed especially for orchard-heating work may be obtained by writing to the Weather Bureau.

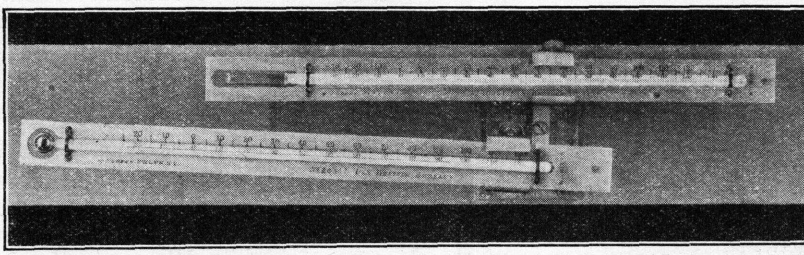


FIG. 38.—Types of thermometers used by the Weather Bureau to register the highest and lowest temperature

For handling the protection of large orchards a thermograph will be very helpful. A satisfactory type for this purpose can be obtained for approximately $100.

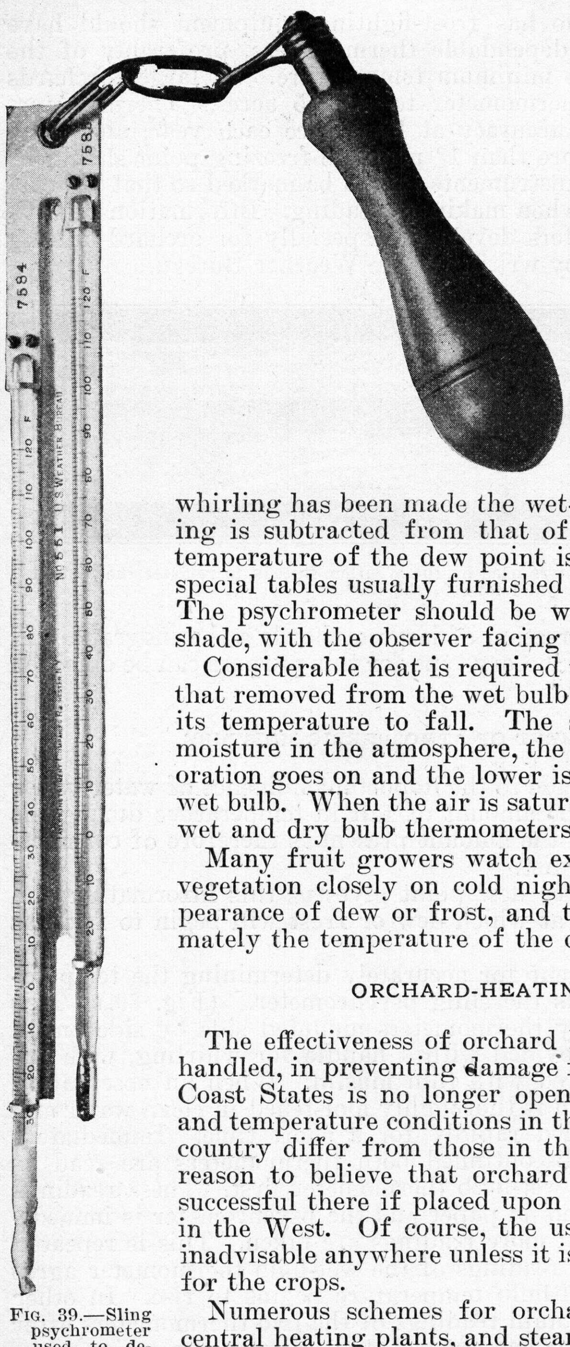
MEASUREMENT OF ATMOSPHERIC MOISTURE

Reference has been made to the important influence of water vapor in the atmosphere on the amount of fall in temperature during the night. A knowledge of the amount present is therefore of considerable value to the orchardist.

The temperature of the dew point gives us this information and also indicates the point at which dew or frost will begin to form as the temperature falls.

The simplest instrument for accurately determining the temperature of the dew point is the sling psychrometer. (Fig. 39.) This consists of two ordinary thermometers mounted side by side on an aluminum strip and provided with a handle for whirling, with the bulb of the lower covered with thin muslin. When an observation is to be made, the muslin is thoroughly moistened in clean water and the instrument is whirled rapidly for a short time. Immediately after the whirling is discontinued both thermometers are read as quickly as possible, the wet-bulb thermometer first. These readings are kept in mind or noted on paper and the psychrometer is immediately whirled again, and more readings are taken. This is repeated several times, until two readings of the wet-bulb thermometer agree closely, or until the wet-bulb temperature begins to rise. In other words, it is desired to obtain readings of the two thermometers after the wet-bulb thermometer has reached its maximum depression.

If the wet-bulb temperature falls to 32° F. and remains at that point, the whirling should be continued for some time later, even



though two or three successive whirlings fail to cause it to read lower. When the water in the muslin begins to freeze, sufficient latent heat is liberated to keep the temperature at 32° F. until all the water on the thermometer bulb is frozen. After this occurs the evaporation from the ice may cause the wet-bulb thermometer to read below 32° F.

After the final whirling has been made the wet-bulb temperature reading is subtracted from that of the dry bulb and the temperature of the dew point is found by referring to special tables usually furnished with the psychrometer. The psychrometer should be whirled and read in the shade, with the observer facing the wind.

Considerable heat is required to evaporate water, and that removed from the wet bulb for this purpose causes its temperature to fall. The smaller the amount of moisture in the atmosphere, the more rapidly the evaporation goes on and the lower is the temperature of the wet bulb. When the air is saturated the readings of the wet and dry bulb thermometers are the same.

Many fruit growers watch exposed weeds and other vegetation closely on cold nights to note the first appearance of dew or frost, and thus determine approximately the temperature of the dew point.

ORCHARD-HEATING NOTES

The effectiveness of orchard heating, when properly handled, in preventing damage from frost in the Pacific Coast States is no longer open to question. Weather and temperature conditions in the eastern portion of the country differ from those in the West, but there is no reason to believe that orchard heating would not be successful there if placed upon as systematic a basis as in the West. Of course, the use of orchard heaters is inadvisable anywhere unless it is justified by the returns for the crops.

Numerous schemes for orchard protection, such as central heating plants, and steam heat, have proved unsuccessful. Orchard heating is at present the only efficient and successful method of protecting orchards from frost damage on a large scale.

FIG. 39.—Sling psychrometer used to determine the amount of moisture in the atmosphere

The fact can not be emphasized too strongly that if orchard heating is to be practiced successfully, it must be handled with as much care and attention as spraying, fumigating, or any other necessary farm work. The secret of success will be found in adequate equipment, good judgment, attention to detail, and extreme vigilance. An inadequate number of fires to the acre may often be worse than none at all, as the costs of firing may have to be added to the loss of the crop.

Whenever the temperature approaches the danger point the thermometer in the orchard should be watched closely, and, if possible, the rate at which the temperature is falling should be determined. If the temperature is falling rapidly the firing must be begun early so that the initial lighting may be completed before the danger point is reached.

Oil heaters (except the lard-pail type) should never be burned dry, as the bowls are likely to be warped and otherwise damaged by overheating.

When heating an orchard, a safe temperature should always be maintained. Frost markings or partial destruction of the crop may result in a loss greater than the entire heating expenses for the season.

Whenever it is possible, the owner of the property should supervise orchard-heating operations. The detailing of the responsibility for the protection of the crop to someone who has no direct interest in the result has been responsible for many failures.

In sections where orchard heating is an established practice and the correct methods of handling the firing are well known, the few failures to save crops are practically all due to carelessness. As a precautionary measure it is well to do a little test firing at the beginning of the season, to make sure that the torches and other equipment are in working order. Defects may be found that can easily be remedied in daylight, but which would cause the loss of much valuable time on a cold night.

The purchase of cheap thermometers is false economy. Buy good thermometers, graduated to single degrees, and guaranteed by the manufacturer to be accurate within one-half degree.

Thermometers should be removed from the orchard at the end of the frost season and stored in a cool place in a vertical position, with the bulbs down.

It is well to place a white stake at the end of the row in which a thermometer is located to facilitate making temperature readings.

During a cold night an isolated cloud passing overhead, may cause the temperature to rise, but as the cloud drifts toward the horizon the temperature falls again. Likewise, sudden temporary rises are caused by gusts of wind of short duration which mix the upper and the surface air. (Fig. 2.) As a general rule the temperature falls rapidly after the wind or cloud has passed; cases are on record where entire crops were lost through extinguishing the heaters at such a time. If clouds are overspreading the entire sky or a sudden rise in temperature due to wind occurs just before sunrise, the heaters may be extinguished, but if the sky remains clear and sunrise is an hour or more away, the temperature should be watched closely during the remainder of the night.

Although it is sometimes difficult to find time to keep records on heating operations during the rush of the firing, it should be done whenever possible. The temperature when firing is begun, time of initial firing and number of heaters fired, time of firing additional heaters, and the lowest temperature recorded during the night can all be jotted down from time to time as the work goes on. On the following day an estimate can be made of the amount of fuel consumed and the extent of the damage to the fruit, if any. Records of this kind will be found to be of great value in regulating later firing; the more information of this kind gathered the more efficiently can the firing be handled.

A good frost alarm of the closed-circuit type is quite dependable and will save considerable watching during the night.

FROST AND MINIMUM TEMPERATURE FORECASTS

General forecasts of frost for large areas are issued by the Weather Bureau during the growing season, and in certain rather small districts where protection against frost damage is practiced on a large scale a more intensive service is maintained. Farmers or fruit growers who have means of protecting their crops should arrange with the nearest Weather Bureau station to obtain forecasts for their community.

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